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ABSTRACT

This individualized learning module on electrical current is one in a series of modules for a course in basic electricity and electronics. The course is one of a number of military-developed curriculum packages selected for adaptation to vocational instructional and curriculum development in a civilian setting. Five lessons are included in the module: (1) Electricity and the Electron, (2) Electron Movement, (3) Current Flow, (4) Measurement of Current, and (5) The Ammeter. Each lesson follows a typical format including a lesson overview, a list of study resources, the lesson content, a programmed instruction section, and a lesson summary. (Progress checks are provided for each lesson in a separate document, CE 026 562.) (LRA)

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ED190878

NAVEDTRA 34258-1

CHIEF OF NAVAL EDUCATION AND TRAINING

MARCH 1977

Military Curricula for Vocational & Technical Education

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM.

MODULE ONE. ELECTRICAL CURRENT.

STUDY BOOKLET.

CE 026 563

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
NATIONAL INSTITUTE OF EDUCATION

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THE NATIONAL CENTER
FOR RESEARCH IN VOCATIONAL EDUCATION
THE OHIO STATE UNIVERSITY

MILITARY CURRICULUM MATERIALS

The military-developed curriculum materials in this course package were selected by the National Center for Research in Vocational Education Military Curriculum Project for dissemination to the six regional Curriculum Coordination Centers and other instructional materials agencies. The purpose of disseminating these courses was to make curriculum materials developed by the military more accessible to vocational educators in the civilian setting.

The course materials were acquired, evaluated by project staff and practitioners in the field, and prepared for dissemination. Materials which were specific to the military were deleted, copyrighted materials were either omitted or approval for their use was obtained. These course packages contain curriculum resource materials which can be adapted to support vocational instruction and curriculum development.

Military Curriculum Materials Dissemination Is . . .

an activity to increase the accessibility of military-developed curriculum materials to vocational and technical educators.

This project, funded by the U.S. Office of Education, includes the identification and acquisition of curriculum materials in print form from the Coast Guard, Air Force, Army, Marine Corps and Navy.

Access to military curriculum materials is provided through a "Joint Memorandum of Understanding" between the U.S. Office of Education and the Department of Defense.

The acquired materials are reviewed by staff and subject matter specialists, and courses deemed applicable to vocational and technical education are selected for dissemination.

The National Center for Research in Vocational Education is the U.S. Office of Education's designated representative to acquire the materials and conduct the project activities.

Project Staff:

Wesley E. Budke, Ph.D., Director
National Center Clearinghouse

Shirley A. Chase, Ph.D.
Project Director

What Materials Are Available?

One hundred twenty courses on microfiche (thirteen in paper form) and descriptions of each have been provided to the vocational Curriculum Coordination Centers and other instructional materials agencies for dissemination.

Course materials include programmed instruction, curriculum outlines, instructor guides, student workbooks and technical manuals.

The 120 courses represent the following sixteen vocational subject areas:

- Agriculture
- Aviation
- Building & Construction Trades
- Clerical Occupations
- Communications
- Drafting
- Electronics
- Engine Mechanics
- Food Service
- Health
- Heating & Air Conditioning
- Machine Shop
- Management & Supervision
- Meteorology & Navigation
- Photography
- Public Service

The number of courses and the subject areas represented will expand as additional materials with application to vocational and technical education are identified and selected for dissemination.

How Can These Materials Be Obtained?

Contact the Curriculum Coordination Center in your region for information on obtaining materials (e.g., availability and cost). They will respond to your request directly or refer you to an instructional materials agency closer to you.

CURRICULUM COORDINATION CENTERS

EAST CENTRAL
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The National Center Mission Statement

The National Center for Research in Vocational Education's mission is to increase the ability of diverse agencies, institutions, and organizations to solve educational problems relating to individual career planning, preparation, and progression. The National Center fulfills its mission by:

- Generating knowledge through research
- Developing educational programs and products
- Evaluating individual program needs and outcomes
- Installing educational programs and products
- Operating information systems and services
- Conducting leadership development and training programs

FOR FURTHER INFORMATION ABOUT
Military Curriculum Materials
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Military Curriculum Materials for Vocational and Technical Education

Information and Field Services Division

The National Center for Research in Vocational Education

O V E R V I E W

MODULE ONE
ELECTRICAL CURRENT

In this module you will be introduced to some fundamental concepts of electricity. You will learn what electrical current is and does, how to build a simple circuit, and how to measure current in that circuit.

For you to more easily learn the above, this module has been divided into the following five lessons:

Lesson I.	Electricity and the Electron	. . . . .
Lesson II.	Electron Movement	. . . . .
Lesson III.	Current Flow	. . . . .
Lesson IV.	Measurement of Current	. . . . .
Lesson V.	The Ammeter	. . . . .

Do not be concerned at this time with names or terms unfamiliar to you. Each will become clear as you proceed. However, if you have any questions, do not hesitate to call your instructor. Turn to the following page and begin Lesson I.

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

M O D U L E O N E

L E S S O N I

Electricity and the Electron

Study Booklet

OVERVIEW

LESSON I

Electricity and the Electron

In addition to the Module Overview, as you start each lesson, you will find a lesson overview like this one. It is merely an outline of what you will study and learn to do in each lesson. In this lesson you will study and learn about the following:

-what electricity does
-what electricity is
-movement inside a solid wire
-a word on theory
-the electron and two other particles
-the atom
-wire and other materials
-composition of matter
-space between atomic particles

Each of the above topics will be discussed in the order listed. As you proceed through this lesson, observe and follow directions carefully.

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON I
Electricity and the Electron

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

- Lesson Narrative
- Programmed Instruction
- Lesson Summary

ENRICHMENT MATERIAL:

Boeke, K. Cosmic View: The Universe in 40 Jumps. New York: The John Day Company, 1957.

NAVPERS 93400A-1a "Basic Electricity, Direct Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.; U.S. Government Printing Office, 1965.

Remember, you may study all or any of these that you feel are necessary to answer all Progress Check questions correctly. Do not forget that in one sense of the word your instructor is a living resource; perhaps the best. Call him if you have any kind of a problem.

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

NARRATIVE
LESSON 1

Electricity and the Electron

What Electricity Does

Most of us know what electricity does. It makes telephones, radios, televisions, toasters, and washing machines work, to name a few. Without electricity, cars, trains, and ships will not move. Electricity makes the lamp on your power supply and the light in your classroom glow. We know what electricity does, but what is electricity itself? Let's see if we can find the answer.

Finding Out What Electricity Is

To first find out what electricity is, think of it as coming through wires. Whether it be your television set, or your toaster, or the light in your classroom or on your power supply, the electricity is carried through wires. Without wires carrying energy, none of these would work. Remember when you plugged your power supply into the outlet in the wall? Not only are there wires on your power supply, but there are wires inside the wall leading to the outlet. There are also wires inside the wall that lead to the on-off switch that turns on the light in your classroom. Therefore, to learn what electricity is, let's first consider the wires that carry this electricity.

At this time, disconnect any wire from your power supply. Look at the end of it. Does it seem solid or hollow?

The answer is: "The wire seems solid."

Movement Inside a Solid Wire

It is perhaps much easier to see what electricity is by visualizing it inside a wire. Although this wire is not hollow like a water hose through which water flows, scientists tell us there is movement within this solid wire. The question is, "How can this be?" You can't see anything moving; you can't feel anything moving. When we say something is moving, we mean something is flowing like a current of water. For the moment, then, let's assume the truth of what the scientists say, that there is movement or flow within a wire.

A Word on Theory

We refer to this movement or flow within a wire as a theory because it cannot be directly observed by seeing, hearing, smelling, or feeling. The movement cannot be verified by your senses. Yet this scientific theory explains how electricity works, and is verifiable by indirect measurement and observation.

The Electron

In their theory of explaining what electricity is and how it works, the scientists use the concept of the electron. In their theorizing, scientists see this electron as a particle that can move. It is a submicroscopic particle, that is, it is too small to see even with the most powerful microscope made.

The Electron and Two Other Particles

Also within that wire are billions and billions of two other particles. These other two particles are usually found with the electron. Scientists have named these other two particles the neutron and proton. The electron, neutron, and proton can be visualized as looking somewhat like this:

The neutron and proton are represented by the n and p circles; the electron is the one labled e. Scientists believe that all electrons are exactly alike, all protons are alike, and all neutrons are alike.

The Atom

For a moment, think of the major parts of our solar system: the sun and the planets. While there are several parts, together they make up the full solar system. In the same way, three basic particles called electrons, neutrons, and protons are grouped together and jointly constitute the atom. We refer, then, to the atom as having all three of these component particles.

Wire and Other Materials

Wire is only one kind of material that has atoms made up of electrons, protons, and neutrons. Your pencil is made up of atoms; so is your paper and the wood in your desk. Glass has

atoms, air has atoms, clothes have atoms, water has atoms, bricks have atoms; the fenders on your car, your steering wheel, all are made up of atoms. In other words, all matter has atoms. As stated, all electrons are alike, all protons are alike, and all neutrons are alike. However, you can't use a piece of glass to carry electricity as you can a piece of wire. The difference in materials lies in the number and arrangement of these subatomic particles within the individual atoms.

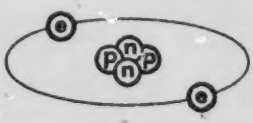
Composition of Matter

In an atom, the neutron and proton are about the same size and weight. They are thought of as being together and forming the nucleus, or center of the atom, as shown:

One Type of Nucleus

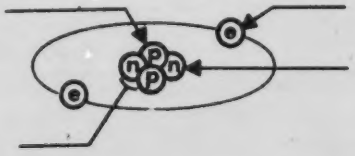
The electron, on the other hand, is much lighter (about 1/1845 the weight of a proton) and orbits about the nucleus at a relatively large distance.

One Type of Atom

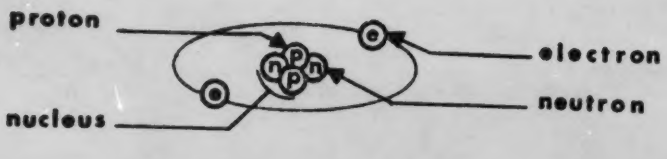


Unless an electron is forced away from its nucleus, it will continue to be part of the atom.

Label these particles of an atom.



Correct answers are:

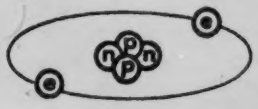


In an atom, the distance separating electrons from the nucleus is about 100,000 times the diameter of the nucleus. The atom is mostly empty space.

Thus far, we have shown you a diagram of a simple atom in order for you to understand the relationship between the electron, neutron, and proton.

However, each kind of material - wood, glass, iron, wire - may have several different kinds of atoms. In fact, there may be many electrons and many neutrons and protons that make up any one type of atom. Remember, however, that the electron is at a relatively large distance from the nucleus.

Materials are made up of a variety of about 100 different elements or kinds of atoms. These many different kinds of atoms in various combinations with each other make up all matter except the atomic particles themselves. The number of particles in the nucleus varies from one kind of material to another. For example, one specific kind of atom has two neutrons and two protons in the nucleus. It is illustrated like this:



In a wire made of copper, the kind you find on your power supply and in the walls, the copper atom has a nucleus that contains 63 particles, and 29 of these are protons.

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON I

Electricity and the Electron

YOU MAY ALREADY KNOW THE INSTRUCTIONAL MATERIAL IN FRAMES 1 to 7. TO FIND OUT, GO TO FRAME 8, WHICH IS A TEST FRAME, AND SEE IF YOU CAN ANSWER ALL THE QUESTIONS THERE. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

---

1. Electrical energy is transferred from one point to another through conductors such as the wires on your power supply.

   Look at the wires on your power supply. They appear to be:

   __ a. hollow
   __ b. solid.

- -

(b) solid

2. Electricity is supplied to the lamp on your power supply by the movement of many billions of tiny particles within the wires.

   These special particles can move:

   __ a. through solid wire.
   __ b. only through hollow wire.

- -

(a) through solid wire.

3. There are many billions of these minute particles moving within a small section of wire. Because of their size, the movement cannot be seen even with a microscope.

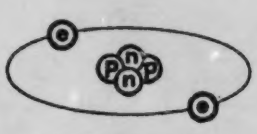
   Electricity can only be fully explained by:

   __ a. a theory.
   __ b. direct observation.

- -

(a) a theory

4. The theory that is used to explain electricity is based on the fact that all matter is made up of atoms, and the atom in turn is composed of particles grouped together as shown below:



How many basic kinds of particles are found in the wire of your power supply?

__ a. six
__ b. four
__ c. three
__ d. two

(c) three

5. The term "electricity" can be associated with the atomic particle that is the most mobile or <u>electrically active</u>.

The particles that move within the wire and cause the lamp to light are:

__ a. protons.
__ b. electrons.
__ c. neutrons.

(b) electrons

6. You can infer that the theory generally used to explain electricity is called the:

__ a. proton theory.
__ b. neutron theory.
__ c. electron theory.

(c) electron theory

7. The electron theory explains electricity as the movement of subatomic particles called _____.

(electrons)

8. Check the correct statements.

___a. Electricity is explained by something you can see.

___b. Electricity is explained by a theory.

___c. A 1/2-inch section of wire that is 1 inch in diameter would contain fewer than 100 particles.

___d. A 1/2-inch section of wire that is 1 inch in diameter would contain many billions of particles.

___e. Particles can move within a solid wire.

___f. Particles can move only through a hollow wire.

___g. Electricity is explained by the movement of protons.

___h. Electricity is explained by the movement of electrons.

___i. Electricity is explained by the movement of neutrons.

- - - -

ANSWERS - TEST FRAME 8

b. Electricity is explained by a theory.

d. A 1/2-inch section of wire that is 1 inch in diameter would contain many billions of particles.

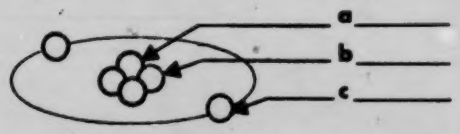
e. Particles can move within a solid wire.

h. Electricity is explained by the movement of electrons.

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 12. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 8 AGAIN.

9. The particle that moves through a wire to make up electricity is the outermost particle.

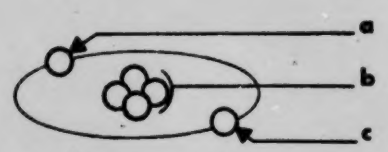
Write the name of this particle on the correct blank below.



(c) electron

10. Protons and neutrons combine to form the nucleus of the atom. The nucleus will always contain one or more protons; neutrons may or may not be present depending on the type of material.

Check the lettered arrow that indicates the nucleus.



(b) nucleus

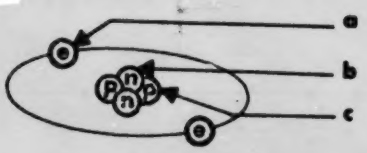
11. In a solid material, the nucleus, for all practical purposes, remains stationary while the electrons are the active particles.

Check the particles which are not very mobile.

__ a. neutrons
__ b. electrons
__ c. protons

(a) neutrons; and (c) protons

12. Label the three particles.



(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 12

a. electron

b. neutron

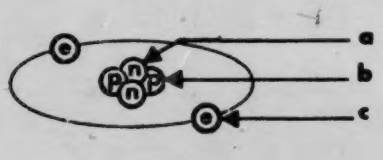
c. proton

Note: All electrons are alike; all protons are alike; and all neutrons are alike.

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 21. OTHERWISE, GO BACK TO FRAME 9 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 12 AGAIN.

13. The particle that has the greatest mobility is the lightest of the three.

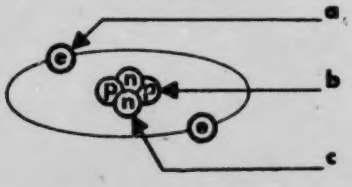
Check the arrow that indicates the lightest particle.



(c) electron

14. The particles in the nucleus are heavier than the particles that move.

Check the heavy particles.



(b) proton; and, (c) neutron

15. Match the following parts in Column B to the characteristics of the parts listed in Column A. Do so by writing the appropriate letters on the blanks provided opposite the numbers.

A	B
___1. light	a. electron
___2. heavy	b. nucleus
___3. in center	
___4. relatively far from the center	

(1. a-electron; 2. b-nucleus; 3. b-nucleus; 4. a-electron)

16. You have seen this diagram.

The dotted line will indicate that the lightest particles are orbiting the other two kinds of particles.

Check the correct statement.

__ a. The neutron orbits the proton and electron.
__ b. The electron orbits the nucleus.
__ c. The proton orbits the nucleus.

(b) The electron orbits the nucleus.

17. The three different kinds of particles make up what is called an atom.

Name the three basic particles of an atom. (Any order)

_____
_____
_____

(electron, proton, neutron)

18. All matter is composed of atoms. Atoms are similar in that they are all composed of the same atomic particles. The difference between types of matter lies in the number and arrangement of these particles.

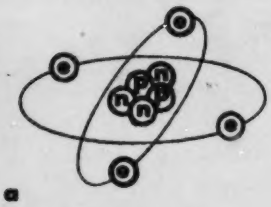
    If we could replace some of the copper nucleus protons with neutrons, the atomic make up of the new wire would be:

    __ a. the same.
    __ b. different.

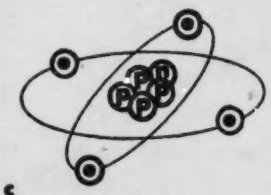
(b) different

19. Regardless of the atomic structure of a material, there will usually be an equal number of electrons and protons in the atoms. This is said to be a normal or neutral condition for the atom.

    Which of the illustrations shows an atom in a neutral state?



a



c

b

d

(c)

20. A copper atom has 34 neutrons and 29 protons.

    How many electrons does it have in its normal condition?

    _____

(29 - same as the number of protons)

21. Match the following:

(Some may require more than one answer.)

___ 1. in nucleus

___ 2. lightest particle

___ 3. farthest from center

___ 4. of equal number in atom

___ 5. orbits nucleus

___ 6. composed of three basic particles

___ 7. most mobile in a wire

a. electron

b. neutron

c. proton

d. atom

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN ON THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 21

1. b-neutron, c-proton
2. a-electron
3. *a-electron
4. a-electron, c-proton
5. a-electron
6. d-atom
7. a-electron

*The relative distance of the atomic electrons from the nucleus is about 100,000 times the diameter of the nucleus.

IF ANY OF YOUR ANSWERS ARE INCORRECT, GO BACK TO FRAME 13 AND TAKE THE PROGRAMMED SEQUENCE.

IF YOUR ANSWERS ARE CORRECT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO ON TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

SUMMARY
LESSON 1

Electricity and the Electron

The energy which causes telephones, radios, washing machines, and toasters to work is called electricity. This electricity comes to most electrically operated devices through wires. In a commercial power system, such as the one supplying your home or this building, these wires form a network that runs all the way from the lights and wall outlets in this room to a main generating plant, possibly hundreds of miles away.

To start your study of electricity, think about the wires that bring electrical energy to the point where it is used. How can energy be carried through a piece of solid metal? The atomic structure of matter supplies the answer to this question. When the submicroscopic appearance of wire is considered, it is found that the wire is not as solid as might be thought. The wire is actually made up of billions and billions of atoms which have relatively large amounts of space in and between them.

To understand what moves inside the wire, you must consider the atoms from which it is formed. According to the atomic theory, all atoms are composed of two basic particles - the electron and the proton, usually existing in equal numbers. In most cases there is also a third particle known as the neutron. The electron is the particle which moves through the wire carrying electrical energy from the generator to the user. In our model of an atom, the electrons orbit the nucleus which is made up of the protons and neutrons.

All materials have an atomic structure, and all atoms contain the same basic particles. The difference in atoms (and materials) is in the numbers of electrons, protons, and neutrons that make up the specific atom.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, SELECT ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

ACCIDENTS
don't just happen—
THEY ARE CAUSED!

DON'T
GET
TURNED
ON
PLAY IT
COOL WITH
ELECTRICITY

BASIC ELECTRICITY AND ELECTRONICS

INDIVIDUALIZED LEARNING SYSTEM

M O D U L E O N E

L E S S O N I I

Electron Movement

Study Booklet

OVERVIEW
LESSON II
Electron Movement

We have seen that electrons are usually bound to an atom. We have also inferred that a flowing stream of electrons constitutes electricity. This lesson will make clear the difference between these two possible states of electrons. In this lesson you will study and learn about the following:

- -movement of particles
- -negative and positive charges
- -neutral particles
- -law of charged bodies
- -random drift

Each of the above topics will be discussed in the order listed. As you proceed through this lesson, observe and follow directions carefully.

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON 11
Electron Movement

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

- Lesson Narrative
- Programmed Instruction
- Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-1a "Basic Electricity, Direct Current."

Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U. S. Government Printing Office, 1965.

You may study whatever learning materials you feel are necessary to answer the questions in the Lesson Progress Check. All your answers must be correct before you can go to Lesson III. Remember your instructor is available at all times for any assistance you may need. YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

NARRATIVE
LESSON 11

Electron Movement

Movement of Particles

Think about the title of this lesson, "Electron Movement." We are speaking here of the movement of the electrons within solid material such as a wire. The other two principle atomic particles, the neutron and proton, are too heavy and too tightly bound together to move around in the wire as freely as the electrons do.

Charges

To understand the movement of electrons, you must understand the term charge. A charge can be defined as "a store or accumulation of force." Two of the three basic atomic particles, the electron and the proton, have a charge and are called charged particles. Some charged particles attract each other and some repel. Let's see which attract and which repel.

Negative and Positive Charges

Recall that the electrons orbit the neutrons and the protons of the atomic nucleus. The electrons do this because their tendency to fly away due to centrifugal force is balanced by an attraction to the protons in the nucleus. The attraction is strong enough to keep the electron within the atom, but not strong enough to draw it to the nucleus. The part to remember here is that the electron is attracted to the proton. Knowing this, let's suppose that we refer to the electron as a negative (-) charge and a proton as a positive (+) charge. They are unlike charges.

Answer this question.

1. Do unlike charges attract or repel?

The answer is that unlike charges attract. The negatively charged electron is attracted to the positively charged proton.

Neutral Particles

As we commonly use the term, anything that is neutral is neither

one way nor the other. A neutral particle is neither attracted nor repelled by other charged (or uncharged) particles. You can observe that word neutral resembles neutron.

Name the atomic particle that is neither attracted nor repelled by other charged particles. _____

The answer, of course, is neutron. It is neither attracted nor repelled by either the electron or proton. The neutron plays no noticeable role in electric current.

Like Charges

We said that the electron has a negative charge and that the proton has a positive charge. Because they are unlike charges, they attract each other. But what about two electrons, both negatively charged, or two protons, both positively charged? The answer is that "like charges repel."

Answer this question.

Which two repel each other?

___ a. two electrons
___ b. two protons
___ c. an electron and proton

The two electrons will repel. They do so because they are "like charges." The same goes for two protons. They are both alike in that they are both positively charged. The answer is "a" and "b".

Law of Charged Bodies

The Law of Charged Bodies states exactly what you have just learned: "Like charges repel, unlike charges attract." This law of charged bodies is part of Coulomb's Law. (The balance of this law tells us "how much" the charges repel or attract.)

We can state this law of Charged Bodies in a number of ways, all meaning the same thing.

Repulsion

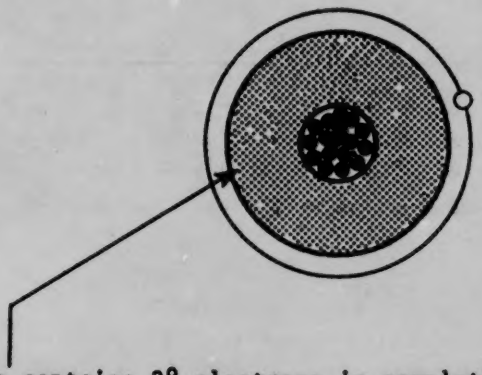
-Like charges repel.
-Two electrons repel.
-Two protons repel.
-A negative and a negative repel.
-A positive and a positive repel.
-A (+) and a (+) repel.
-A (-) and a (-) repel.

Attraction

-Unlike charges attract.
-A proton and an electron attract.
-A positive and a negative attract.
-A (+) and a (-) attract.

Movement Caused by Charges

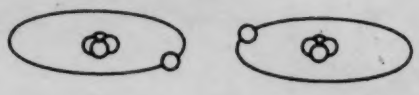
When we speak of movement caused by forces between charges, we are primarily referring to the attraction of the electron to the proton. Recall that we said there are billions and billions of atoms in one single wire of our power supply. We also said that, in this copper wire, each copper atom has 29 electrons. We chose to think of each of these electrons as orbiting the nucleus (neutrons and protons). Of these 29 electrons, some are closer to the nucleus, others are farther away, visualized somewhat like the following illustration.



This volume contains 28 electrons in complete shells around the nucleus of the atom. The outermost orbit of the copper atom contains only <u>one</u> loosely bound electron, as shown.

According to the complete form of Coulomb's Law of charged bodies, all electrons are attracted to the nuclear protons. Since the force of attraction between charged particles lessens with increased distance, the electrons farther from the nucleus experience less force of attraction than those closer to the nucleus. Once again recall that there are billions and billions of atoms. Let's

take just two of these atoms and look at the electrons farthest from the nucleus in each atom.



In observing the two illustrations, remember two points:

1. The outer electrons, although attracted to their respective nuclei, have the weakest force of attraction because they are farthest away.

2. As the outer electrons of each atom approach each other, they will repel each other.

You know this because: (check one)

___ a. like charges repel.
___ b. unlike charges repel.

The answer is "like charges repel."

This force of repulsion between outer electrons of one atom and outer electrons of another atom may become stronger than the attraction of electrons to the protons. Therefore, as the outer electrons approach each other, they repel and may be forced out of their atomic orbits.

When this occurs, the atom is left with more positive charge (protons) than negative charge (electrons) leaving the atom with a net positive charge. This positively charged atom is called a positive ion. If an electron joins an atom that already has a full complement of electrons (a neutral atom), the atom assumes a net negative charge and becomes a negative ion. An ion, then, is simply a charged atom. The process whereby an atom becomes an ion is called ionization. The amount of energy (outside force, such as heat energy, light energy, etc.) necessary to cause ionization for any particular atom is known as the ionization potential.

Random Drift of Electrons

Once an electron has been driven from its atomic orbit it becomes a free electron, drifting here and there seeking a new orbit. This free electron, no longer attracted to its home atom, is now free to drift at random. This movement of free electrons is referred to as random drift. Note that special cases exist at the surface of

the wire, and here other forces tend to keep the electrons within the wire.

RANDOM DRIFT OF ELECTRONS

The diagram above shows electrons moving in all directions. Since this movement of free electrons is at random in all directions, it cannot be used as electricity to light lamps, operate toasters, and so on. For electricity to do something, a majority of these free electrons must be caused to move in one general direction. If this is not the case, there is no net flow of energy, and no work can be done.

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY THE METHOD OF INSTRUCTION YOU PREFER UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON 11

Electron Movement

TEST FRAMES ARE 18, 29, and 35. AS BEFORE, GO FIRST TO TEST FRAME 18 AND SEE IF YOU CAN ANSWER ALL THE QUESTIONS THERE. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

1. Electrons and protons tend to draw together.

   Check the two particles that are attracted to each other.

- -

(b-electron; c-proton)

2. The atomic particles that orbit the nucleus repel each other.

   Which two particles repel?

   ___ a. two neutrons.
   ___ b. two electrons.

- -

(b) two electrons

3. The particles to which electrons are attracted also repel each other.

   Check the other particles that repel each other.

   ___ a. neutron and proton.
   ___ b. proton and electron.
   ___ c. neutron and neutron.
   ___ d. proton and proton.

- -

(d) proton and proton

4. Match the two columns.

___ a. two electrons	1. attract
___ b. two protons	2. repel
___ c. protons and electrons	

(a. 2-repel; b. 2-repel; c. 1-attract)

5. The atomic particles that are not in the nucleus are said to have a negative charge. (Charge means an accumulation or store of force.)

Which particle has a negative charge?

___ a. proton
___ b. electron
___ c. neutron

(b) electron

6. The other kind of particle that attracts and repels is said to have a positive charge.

Which particle has a positive charge?

___ a. proton
___ b. neutron
___ c. electron

(a) proton

7. As its name implies, the third particle is neutral and could be symbolized this way: $(\overset{+}{-})$

A neutron:

___ a. has a net positive charge.
___ b. neither attracts or repels.
___ c. has a net negative charge.

(b) neither attracts or repels.

8. The symbol for negative charge is the minus (-) sign. The symbol for positive charge is the plus (+) sign. The positive sign above the negative sign ($\overset{+}{-}$) indicates the particle is neutral.

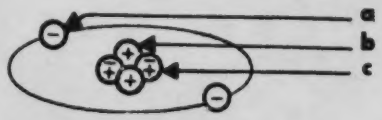
Match.

___ 1. +
___ 2. ($\overset{+}{-}$)
___ 3. -

a. electron
b. proton
c. neutron

(1. b-proton; 2. c-neutron; 3. a-electron)

9. Label each particle according to its charge.



(a-electron; b-proton; c-Neutron)

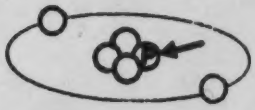
10. Look at the diagram of the atom.

Check the items that are true of the particle indicated by the arrow.

___ a. negatively charged.
___ b. positively charged.
___ c. symbolized by - sign.
___ d. symbolized by + sign.
___ e. attracted to proton.
___ f. repelled by proton.
___ g. attracted to electrons.
___ h. repelled by electrons.
___ i. neutral.

(a-negatively charged; c-symbolized by - sign; e-attracted to proton; h-repelled by electrons)

11. Look at the diagram of the atom.



Check items that are true of the particle indicated by the arrow.

___ a. negatively charged.
___ b. neutral charge.
___ c. symbolized by + sign.
___ d. symbolized by - sign.
___ e. attracted to electron.
___ f. attracted to protons.
___ g. positively charged.
___ h. repelled by protons.
___ i. attracted to protons.
___ j. symbolized by ± sign.

(c-symbolized by + sign; e-attracted to electron; g-positively charged; h-repelled by protons)

12. Match the columns.

___ 1.	negative charge and negative charge	a. attract
___ 2.	positive charge and positive charge	b. repel
___ 3.	negative charge and positive charge	

(1. b-repel; 2. b-repel; 3. a-attract)

13. The word <u>like</u> means <u>of the same kind</u>.

Check the correct statements.

___ a. Like charged particles attract.
___ b. Like charged particles repel.
___ c. Unlike charged particles attract.
___ d. Unlike charged particles repel.

(b-Like charged particles repel; c-Unlike charged particles attract)

14. What is true of the charged particles is also true of groups of charges.

Check the correct statements.

___ a. Groups of like charges repel.
___ b. Groups of unlike charges attract.
___ c. Groups of unlike charges repel.
___ d. Groups of like charges attract.

(a-Groups of like charges repel; b-Groups of unlike charges attract)

15. In electrical theory:

___ a. unlike charges attract.
___ b. like charges repel.

(a-unlike charges attract; b-like charges repel)

16. That unlike charges attract and like charges repel is referred to as the "Law of Charged Bodies." According to the Law of Charged Bodies:

___ a. two electrons repel.
___ b. two protons repel.
___ c. protons and electrons attract.

(a-two electrons repel; b-two protons repel; c-protons and electrons attract)

17. You can infer that the Law of Charged Bodies does not refer to the particle that is neutral.

Write the name of the neutral particle. _____

(neutron)

18. Match

___ 1.	two protons	a.	attract
___ 2.	proton and electron		
___ 3.	(+) and (-)	b.	repel
___ 4.	two electrons		
___ 5.	positive and negative	c.	neither
___ 6.	(+) and (+)		
___ 7.	like charges		
___ 8.	positive and positive		
___ 9.	negative and negative		
___ 10.	unlike charges		
___ 11.	two neutrons		

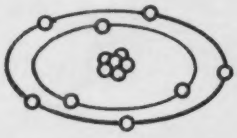
(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 18

1. b	7. b
2. a	8. b
3. a	9. b
4. b	10. a
5. a	11. c
6. b	

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 29. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 18 AGAIN.

19. Study the illustration of an atom below.



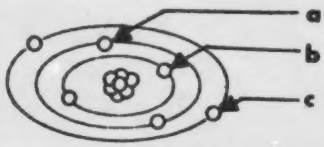
The diagram indicates that electrons:

___ a. are all equal distances from the nucleus.
___ b. may be spaced at different distances from the nucleus.

(b) may be spaced at different distances from the nucleus

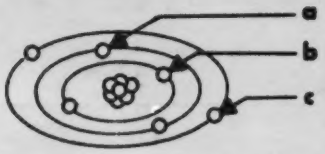
20. Coulomb's Law of Charged Bodies tells us that the greater the distance between the protons in the nucleus and the electron, the weaker the force of attraction between them.

Check the electron that has the weakest force acting upon it.



(c) electron in the outer orbit

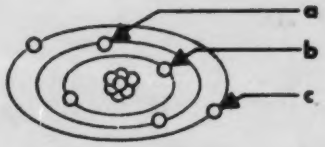
21. Study this diagram. Check the electron that has the strongest force of attraction acting on it.



(b) the electron in the inner orbit

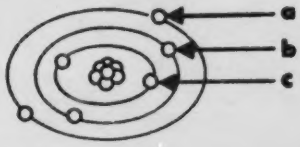
22. Electrons which are weakly attracted to their nucleus can be easily dislodged from their orbits by some external force such as heat energy, light energy, etc.

Check the electron which can be easily dislodged from its orbit by a force.



(c) electron in the outer orbit

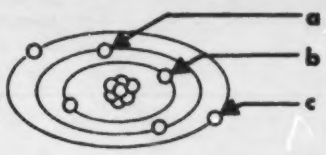
23. Check the electron that would require the most force to be dislodged.



(c) the electron in the inner orbit

24. Electrons which have the weakest force of attraction to their nucleus can more easily become <u>free</u> <u>electrons</u>.

Check the arrow that indicates the electron that could easily become a free electron.



(c) the electron in the outer orbit

25. If an electron is forced from its orbit, the atom is left with more positive charges (protons) than negative charges (electrons) and will assume an overall _____ charge. (positive/negative/neutral)

(positive)

26. If a free electron should become attached to an atom that already has a full complement of electrons, this atom would contain more _____ charges than _____ charges and would assume an overall _____ charge.

(negative; positive; negative)

27. When an atom assumes a charge either by gaining or losing electrons, it becomes a charged atom and is called an <u>ion</u>.

An ion is an atom that no longer has an equal number of _____ and _____.

(protons and electrons)

28. Any charged atom is an ion. An atom that has a deficiency of electrons is a positive ion.

An atom with an excess of electrons is a _____.

(negative ion) .

29. Label the diagram as neutral atom, negative ion, or positive ion.

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 29

a. Neutral; b. Positive; c. Positive; d. Negative

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 35. OTHERWISE, GO BACK TO FRAME 19 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 29 AGAIN.

30. The process whereby an atom becomes an ion is known as ionization. The amount of energy (outside force such as heat energy, light energy, etc.) required to cause ionization is called ionization potential.

In order for an electron to become free of the parent atom, energy equal to or greater than the _____ must be applied to the atom.

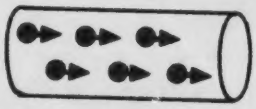
(ionization potential)

31. The free electrons move in all directions within the material. This haphazard movement of free electrons is called random drift.

Which illustration shows the random drift of free electrons?

a

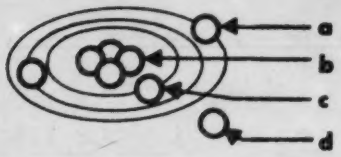
b



(a) random drift

32. A free electron is an electron which has been dislodged from the parent atom.

Check the lettered arrow pointing to the free electron.



- -

(d) the electron not in orbit

33. Which correctly describes free electrons?

___ a. those no longer attached to an atom
___ b. those hard to dislodge from the atom
___ c. those that have become attached to another atom's nucleus

- -

(a) those no longer attached to an atom

34. Random drift:

___ a. is the movement of free electrons together in one direction.
___ b. describes the movement of electrons around the nucleus.
___ c. is the haphazard movement of free electrons.

- -

(c) is the haphazard movement of free electrons

35. Check the correct statements.

___ a. Within an atom having several orbits of electrons, the electrons are all at equal distances from the nucleus.

___ b. The greater the distance between the nucleus and the electron, the weaker the force of attraction between them.

___ c. Electrons weakly attracted to the nucleus are difficult to dislodge from that nucleus.

___ d. Free electrons are those that have the greatest potential of being free when an outside force is applied.

___ e. Random drift is the haphazard movement of atoms in a wire.

___ f. Within an atom having several orbits of electrons, the electrons are spaced at different distances from the nucleus.

___ g. Electrons dislodged from their atoms after an external force has been applied are called free electrons.

___ h. The greater the distance between the nucleus and the electron, the greater the force of attraction between them.

___ i. Random drift is the haphazard movement of protons in a wire.

___ j. Electrons weakly attracted to their nucleus are the easiest to dislodge from their orbits.

- -

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 35

b - The greater the distance between the nucleus and the electron, the weaker the force of attraction between them.

f - Within an atom having several orbits of electrons, the electrons are spaced at different distances from the nucleus.

g - Electrons dislodged from their atoms after an external force has been applied are called free electrons.

j - Electrons weakly attracted to their nucleus are the easiest to dislodge from their orbits.

IF ANY OF YOUR ANSWERS IS INCORRECT, GO BACK TO FRAME 19 AND TAKE THE PROGRAMMED SEQUENCE.

IF YOUR ANSWERS ARE CORRECT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY GO ON TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

SUMMARY
LESSON 11

Electron Movement

The electron may constitute electricity because it has an electric charge. The proton also has an electric charge, but it is opposite in character to the electron's charge. By common agreement, we call the proton's charge positive and that of the electron negative. The neutron is neutral, that is, it has no net charge.

In the last lesson, you learned that electrons are believed to carry the electrical energy. Protons and neutrons are too heavy and too tightly bound together to move around in the wire as freely as the electrons do.

Complex forces hold the electrons in their more stable positions in the atom. It is experimentally found that positive and negative charges attract each other. Another electrical force is the mutual repulsion which exists between electrons. Similar mutual repulsion exists between protons. These forces are stated in Coulomb's Law of Charged Bodies as "like charges repel and unlike charges attract." The protons in the nucleus of an atom are held together by very strong nuclear binding forces; so the protons cannot be separated by the force of repulsion between them. But the orbiting electrons are more delicately balanced. There is a force of attraction between the electrons and the nuclear protons. This force tends to pull the electrons toward the nucleus while the energy of their motion (centrifugal force) tends to move them outward. Normally the two forces will balance and the electrons will remain in orbit about the nucleus, and the atom will maintain its electrical neutral state.

The greater the distance between two unlike charges, such as an orbiting electron and the positive charge of the nucleus, the smaller the force of attraction between the two particles. Because of this, the electrons that orbit farthest from the nucleus may lose this balance of force quite easily and move away from the atom to become free electrons. This will occur when some outside force (heat energy, light energy, etc.) is applied to the atom. Since the electron with its negative charge has left the atom, the atom now contains more positive charges (protons) than negative charges (electrons) and has become a positively charged particle called a positive ion.

If a free electron becomes attached to an atom that already has a full complement of electrons the atom assumes an overall negative charge and is called a negative ion. As you may have gathered, ion is a term used to refer to an atom that has assumed a net negative or positive charge. The process whereby an atom becomes an ion is known as ionization and the amount of energy (outside force) necessary to free an electron from its atom is known as the ionization potential for that atom.

Once an electron leaves its orbit and becomes a free electron, it drifts at random through the material until some other force (a positive charge, repulsion from another electron, attraction to an atom which has lost an electron, etc.) acts upon it. This movement of free electrons is called random drift, and because this movement within a material takes place in all directions, the average net effect is zero; nothing can be measured and no electrical work is done.

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED LESSON. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY THE METHOD OF INSTRUCTION YOU PREFER UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

BASIC ELECTRICITY AND ELECTRONICS

INDIVIDUALIZED LEARNING SYSTEM

M O D U L E O N E

L E S S O N I I I

Current Flow

Study Booklet

OVERVIEW
LESSON III

Current Flow

In this lesson you will study and learn about the following:

- -random drift vs. directed drift
- -directing electron movement
- -current path
- -simple circuits
- -introduction to schematics
- -direction of current flow
- -building a simple circuit

Each of the above topics will be discussed in the order listed. As you proceed through this lesson, observe and follow directions carefully.

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES

LESSON III

Current Flow

To learn the material in this lesson, you have the option of choosing, according to your experience and your preferences, any or all of the following:

STUDY BOOKLET:

Lesson Narrative
Programmed Instruction
Lesson Summary

ENRICHMENT MATERIAL:

Boeke, K. Cosmic View: The Universe in 40 Jumps.
New York: The John Day Company, 1957.

NAVPERS 93400A-1a "Basic Electricity, Direct Current."
Fundamentals of Electronics. Bureau of Naval Personnel.
Washington, D.C.: U. S. Government Printing Office, 1965.

AUDIO-VISUAL:

Sound/Slide Presentation: "Constructing a Simple Circuit."

You may study whatever learning materials you feel are necessary to answer the questions in the Lesson Progress Check. All your answers must be correct before you can go to Lesson IV. Remember, your instructor is available at all times for any assistance you may need.

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

NARRATIVE
LESSON III

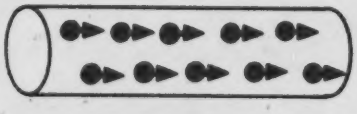
Current Flow

Random Drift vs. Directed Drift

In the previous lesson we spoke of random drift, which you recall was the movement of the outermost electron away from its atomic nucleus. Disconnect a wire from your power supply, pick it up, and look at it. Inside that wire there is a random drift of billions of free electrons. In this state, these free electrons are not capable of doing anything useful, meaning they cannot make lamps light or machines operate or household appliances work. This is true if all the wires are connected but your power supply cord is not plugged in, or if the switch is open. To obtain electrical current, the free electrons drifting at random must be moved in one general direction. Directing and controlling this movement is referred to as directed drift.

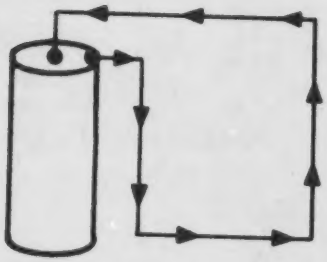
Directing Electron Movement

To control and direct the drift of these free electrons, some external force or push is necessary. We will discuss later the force that causes these electrons to move in one direction. For now, we merely want you to know that we cannot have electrical current (electron flow) that will do work unless these free electrons are moving in one general direction. From here on, when we speak of electrical current, we will mean directed electron flow capable of doing work. Net electron flow must be directed like this:

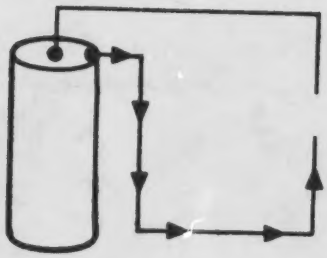


Current Path

To direct this flow of electrons and thus form electrical current capable of doing work, there must be a complete path for the electrons to take. That is, they must leave the source, follow a complete path and return to the source. The following illustration shows the difference between a complete path and an incomplete path. Remember, the complete path must include a return to the source.



A



B

In which illustration above will current flow and do some work?

(Check one)

___ a. Illustration A
___ b. Illustration B

Answer: a. Illustration A

Circuits

For the electrons to flow continuously in one direction they must have a complete path to follow. This path is called a circuit. When all wires in your power supply are connected and the cord plugged in, electrons have a complete path. You now have an electrical circuit capable of doing work - lighting the lamp.

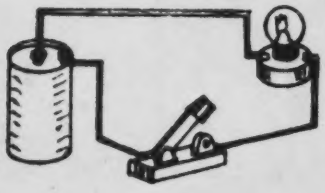
Since the wires form a path for conducting the electrons through the wires, they are referred to as conductors. If there is not a complete path for the electrons to move around the circuit due to an open or break in the conducting path, the directed electron movement stops, and, in effect, you have no current.

Diagram of a Simple Circuit

Soon, you will be constructing a simple circuit. A simple circuit usually has one source, such as a battery, that provides the force to cause directed electron flow. Wires will be connected to make a complete path for current, and there will be a workload that will use the current. In the simple circuit you build, the load will be a lamp. There will be one other component --

a knife switch, that can be used to break or complete the path of current flow.

We could draw a pictorial diagram of a simple circuit like this, illustrating a dry cell, a lamp, a switch, and connecting wires that conduct the current through the circuit.

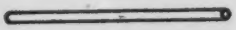


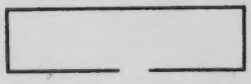
It would be difficult to illustrate more complex circuits in this manner. Instead, we use diagrams referred to as schematics. A schematic of a simple circuit above looks like this:

Some Schematic Symbols

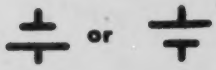
As you observed, we use certain symbols to represent certain components or parts of a circuit.

Wire or conductor is symbolized by straight connecting lines.



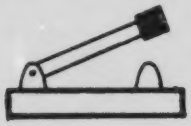


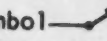
A dry cell is symbolized by two short lines of unequal length, separated by a space, and showing a conductor connected to each line:



A lamp is symbolized by a small loop in the conductor that has a circle around it:

An open switch is symbolized like this:

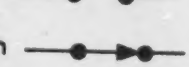


This open switch symbol  indicates that the circuit is broken or open and no current can flow because the blade of the switch is not touching the metal contact.

A closed switch is symbolized like this:

You can see that when the switch is closed, there is a complete path for current.

Open switch open circuit - no current

Closed switch  closed circuit - current flow

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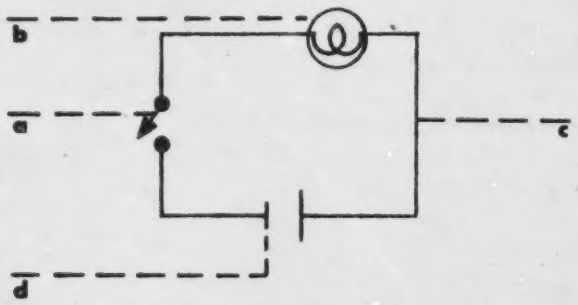
Without looking back, see if you can identify the symbols on this schematic by writing the names of the parts they represent on the dotted lines.

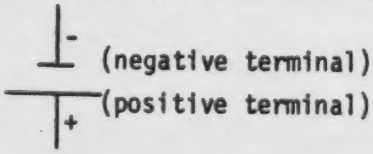


You should have labeled the components like this:

a. switch (open)
b. lamp
c. wire or conductor
d. dry cell

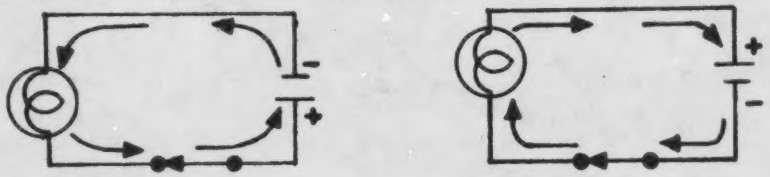
Direction of Current Through A Circuit

Recall that the schematic symbol for a cell is two lines of unequal length. This is significant. By common agreement, the shorter line represents the negative terminal of the cell, while the longer line represents the positive terminal.



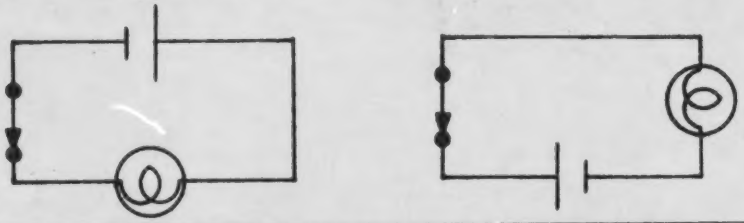
You remember that electrons have a negative charge, and therefore they are pushed out of the negative terminal of the battery. This means that we can determine the direction of current flow of a circuit by locating the short line of the battery symbol in a schematic.

Electron current flows from the negative terminal, through the conductor and circuit components, and back to the positive terminal in this manner:



Observe the arrows that show current flow from negative to positive.

Draw arrows to indicate direction of electron current flow in these circuits.



In both circuits, current will flow from the negative to the positive terminal and your arrows should show counterclockwise flow in both cases.

Since electrons cannot be seen, a guess was taken almost two centuries ago as to whether (+) charges or (-) charges constituted current. Unfortunately, the wrong guess was made. Many books still use the conventional theory of a current of (+) charges moving from the positive terminal of the cell. The results are equivalent, but do not agree with the more modern theory.

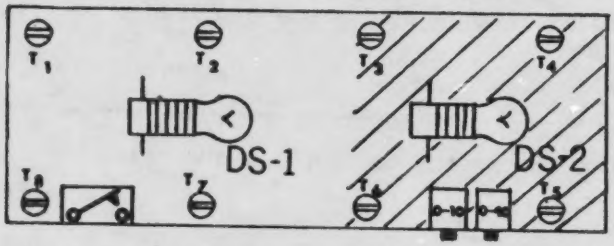
Building Your Simple Circuit

Your simple circuit will consist of these components:

- -a dry cell
- -three conductors
- -a vector board
- -a preassembled knife switch

IF YOU DO NOT ALREADY HAVE THESE ITEMS AT YOUR CARREL, GO NOW TO THE MATERIALS CENTER AND ASK FOR YOUR "SIMPLE CIRCUIT" PACKAGE FOR MODULE ONE.

Spread the materials you need in front of you. Particularly notice the vector board. You will use this board many times in your study. Observe that it looks like this:



Each spring clip is labeled by number -- T1, T2, etc. The two premounted lamps are labeled DS1 and DS2. DS is a standard abbreviation for lamp which you will find on schematics.

Also observe that a knife switch is premounted between T8 and T7.

During the first modules of this course you will be using only the left half of the vector board. The right half, which is shaded in the above drawing, you will use later.

Now let's build a circuit!

Place the vector board in front of you so that labels are readable, not upside down.

Perform the following steps in order:

---

1. Open the switch by pulling the handle up.
2. Take one wire conductor and connect it to the center terminal of the dry cell. (This is the + terminal.) Do this by wrapping a bare end around the post, and then tightening the screw.
3. Take a second conductor and connect it to the outside, or negative terminal of the cell.
4. Connect the loose end of the wire from the negative terminal of the cell to spring clip T1.
5. Connect the loose end of the wire from the positive terminal of the cell to T8.
6. Take the third wire and connect it between T1 and T2.
7. Connect the loose end of the top wire from DS1 (the one closest to T2) to T2.

8. Connect the loose end of the bottom wire from DS1 to T7.
9. Connect the wires from each end of the switch to T7 and T8.

Now you have constructed a simple circuit. Look at it to see that you have made all connections and provided a complete path for current.

---

10. Now close the switch to complete the path.

YOUR LAMP SHOULD LIGHT.

11. Close and open the switch several times. Observe that as the metal part of the switch touches the metal contact, the circuit is closed, and the lamp lights. As contact is broken, the circuit is open, no current can flow, and the lamp does not work.
12. Finally, open the switch and leave the circuit as it is. (You will use it again in the next lesson.)
13. Draw a schematic to represent the simple circuit you have constructed. Include the symbols for:

    1. the cell
    2. the conductor
    3. switch
    4. lamp

Then draw arrows on your schematic to indicate the direction that current would flow if the switch were closed.

Check your schematic against the one shown below.

Your schematic should look like this:

Observe that current would flow from negative to positive.

YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON III

Current Flow

TEST FRAMES ARE 7, 10, 21, 25, and 29. AS BEFORE, GO FIRST TO TEST FRAME 7 AND SEE IF YOU CAN ANSWER ALL THE QUESTIONS THERE. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

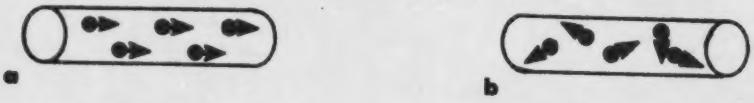
1. Random drift was described as:

___ a. free electrons that move haphazardly.
___ b. free electrons that attach to another atom.
___ c. free electrons that move together in the same general direction.

(a) free electrons that move haphazardly

2. Free electrons drifting at random are not capable of doing useful work.

Check the illustration that shows electrons not capable of lighting a lamp or operating a motor.



(b) random drift

3. To be capable of doing useful work, free electrons must be directed by some force into moving in one general direction.

Check the illustration that shows directed electron drift.

(b) directed movement

4. Dry cells, batteries, and the voltage from electrical wall outlets are sources of electrical energy and can supply the force needed to cause directed electron drift.

   Check the item that shows a force being applied to electrons.

   ____ a

   ____ b

(b)

5. Continuous electrical current is the movement of free electrons in the same general direction.

   Current flow is:

   ___ a. random drift.
   ___ b. directed drift.

(b) directed drift

6. Current flow:

   ___ a. is capable of lighting a lamp.
   ___ b. is not capable of doing useful work.

(a) is capable of lighting a lamp

7. Check the items that correctly describe current flow.

   ___ a. random drift of free electrons
   ___ b. electrons attached to parent atom
   ___ c. directed drift of free electrons
   ___ d. free electrons doing work
   ___ e. free electrons not capable of doing work
   ___ f. free electrons not forced into moving in one direction

---

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 7

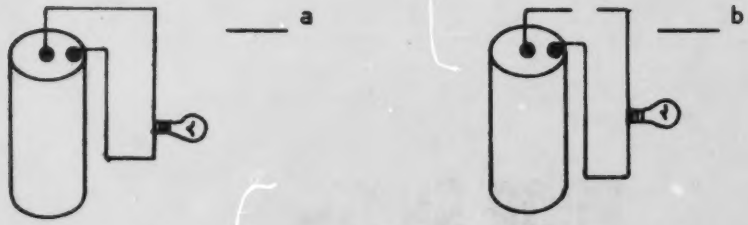
c - directed drift of free electrons

d - free electrons doing work

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 10. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 7 AGAIN.

8. For current flow to take place, electrons must have a continuous path to move through.

Check the illustration in which there can be no continuous current flow.



(b)

9. A continuous path for electrons to follow is called a complete circuit.

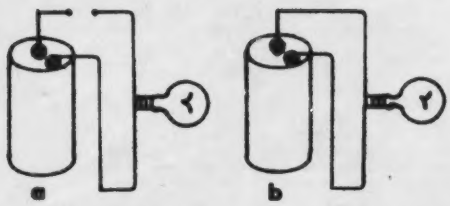
An incomplete circuit:

___ a. is capable of doing work.
___ b. is not capable of doing work.

(b) is not capable of doing work

10. Match the illustration to the circuit condition.

___ 1. current will flow
___ 2. complete circuit
___ 3. is not doing work
___ 4. continuous path for electrons
___ 5. incomplete circuit
___ 6. is doing work
___ 7. no current flow
___ 8. broken path



- -

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 10

1. b	5. a
2. b	6. b
3. a	7. a
4. b	8. a

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 21. OTHERWISE, GO BACK TO FRAME 8 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 10 AGAIN.

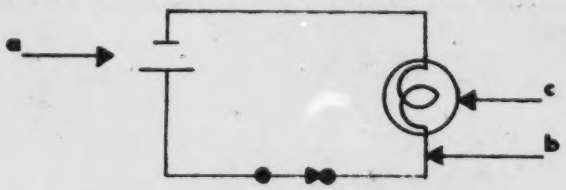
11. A schematic (pronounced ske-mat-ic) is an organized drawing of a circuit that uses generally accepted electrical symbols to represent actual parts of a circuit.

This is a _____ diagram.

(schematic)

12. The wires that form a path for conducting electrons through the circuit are referred to as conductors and are symbolized by solid connecting lines.

Check the arrow that indicates a conductor.



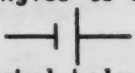
(b) is a conductor

13. A light bulb or lamp, which is the load (uses electrical energy) in your circuit, is symbolized by a circle around a small loop in the conductor.

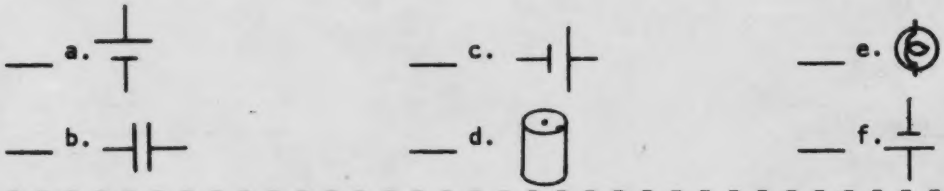
Check the schematic symbol for the load in your circuit.

(c)

14. A dry cell, which is the source (supplies electrical energy) for your circuit, is symbolized in a schematic by two short lines of unequal length, separated by a space, and including a length of conductor at right angles to each line as shown here:



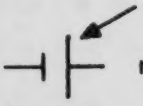
Check each schematic symbol below that represents a dry cell.



(a, c, f)

15. The longer line of the dry cell symbol represents the positive terminal of the cell.

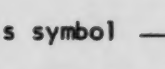
Study the diagram.

The longer line of this symbol  represents:

___ a. the center terminal of the cell.
___ b. the outer terminal of the cell.

(a) the center terminal of the cell

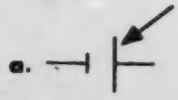
16. The short line of the dry cell symbol represents the other terminal of the cell.

The short line of this symbol  represents:

___ a. the positive terminal.
___ b. the negative terminal.
___ c. the outer terminal of the cell.
___ d. the center terminal of the cell.

(b-the negative terminal; c-the outer terminal of the cell)

17. Match the arrowed part of the symbol to the corresponding items.

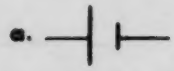
a. 

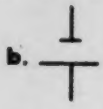
___ 1. center post of cell
___ 2. positive terminal
___ 3. negative terminal
___ 4. outer post of cell

b.

(1-a, 2-a, 3-b, 4-b)

18. Label each schematic symbol with a minus (-) sign and a plus (+) sign beside the representative lines of the symbol.

a. 

b. 

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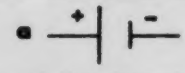
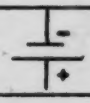
a 

b 

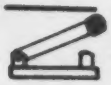
19. The schematic symbol for a switch is an arrow between two dots. It may appear in different positions.

Check the schematic symbols for a switch.

___ a.

___ b.

___ c.

___ d. 

___ e.

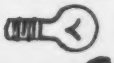
___ f.

___ g.

(b, e, f)

20. Match the schematic symbols to the objects they represent.

___ 1.

___ 2. 

___ 3.

___ 4.

a.

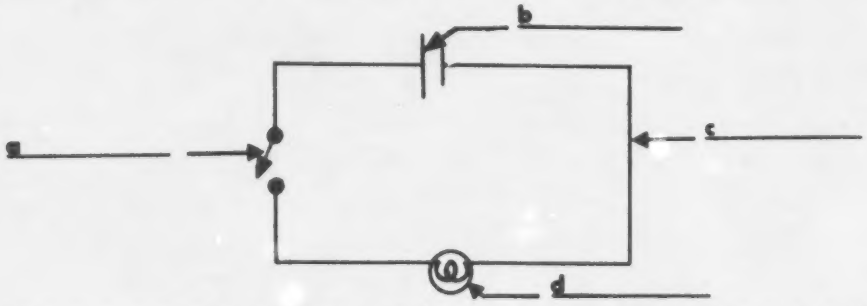
b.

c.

d.

(1-c, 2-d, 3-b, 4-a)

21. Write the name of each symbol on the indicating arrow.



(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 21

a. switch (open)

b. dry cell or cell (positive terminal)

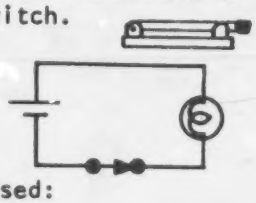
c. conductor or wire

d. lamp or light bulb

- -

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 25. OTHERWISE, GO BACK TO FRAME 11 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 21 AGAIN.

22. The schematic below shows the switch in a closed position such as this actual switch.



Study the schematic.

When the switch is closed:

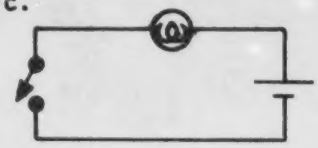
___ a. electrons cannot move through the circuit.
___ b. the lamp lights.
___ c. the circuit is complete.
___ d. the circuit is open.
___ e. current flows.

- -

(b-the lamp lights; c-the circuit is complete; e-current flows

23. This schematic shows the switch in an open position such as this actual switch:

Study the schematic.



When the switch is open:

___ a. the circuit is closed.
___ b. current stops.
___ c. the lamp lights.
___ d. there is a continuous path for electrons to move through.
___ e. the circuit is open.

(b- current stops; e- the circuit is open)

24. Match the correct switch symbol to the terms.

___ 1. open switch
___ 2. closed switch
___ 3. allows current flow
___ 4. stops current flow

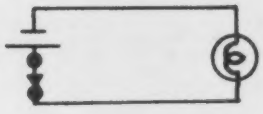
a.

b.

(1-a, 2-b, 3-b, 4-a)

25. Match the schematic diagrams to the circuit conditions.

___ 1. light on
___ 2. light off
___ 3. switch open
___ 4. switch closed
___ 5. allows current flow
___ 6. stops current flow
___ 7. open circuit
___ 8. complete circuit

a. 

b.

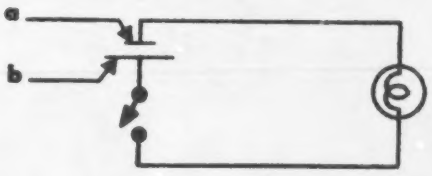
(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 25

1. a	5. a
2. b	6. b
3. b	7. b
4. a	8. a

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 29. OTHERWISE, GO BACK TO FRAME 22 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 25 AGAIN.

26. When the switch is open in the circuit as shown below, an excess of electrons piles up at the negative terminal of the cell and any parts connected to it.



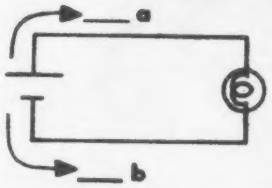
When the circuit is open, an excess of electrons exists at the point:

___ a. indicated by arrow a.
___ b. indicated by arrow b.

(a) indicated by arrow a

27. When the switch is closed, the force of repulsion between the negatively charged particles pushes electrons away from the negative terminal. This push, combined with the attraction between the positive terminal and the electrons, forces the electrons through the circuit to the positive terminal of the cell.

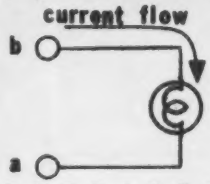
Check the lettered arrow that shows the direction of current flow in this circuit.



(b)

28. The movement of negative charges (electrons) from a negative point to a positive point is a statement of the electron theory of current flow.

With no indication given, determine which point is negative and which is positive.

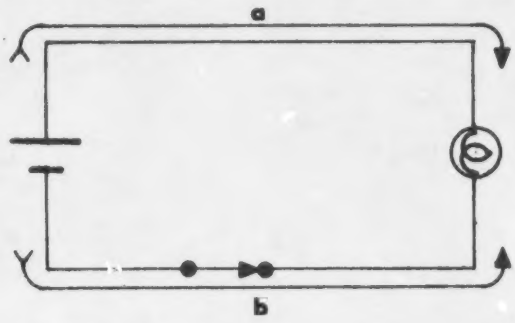


a. _____
b. _____

- -

(a. + positive; b. - negative)

29. Study this diagram.



Check the statements that are true.

___ a. Electron current will flow in the direction shown by arrow a.
___ b. Electron current will flow in the direction shown by arrow b.
___ c. Electron current will flow from positive to negative through the circuit.
___ d. Electron current will flow from negative to positive through the circuit.

- -

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 29

b - Electron current will flow in the direction shown by arrow b.

d - Electron current will flow from negative to positive through the circuit.

Since electrons cannot be seen, a guess was taken almost two centuries ago as to whether (+) charges or (-) charges constituted current. Unfortunately, the wrong guess was made. Many books still use the conventional theory of a current of (+) charges moving from the positive terminal of the cell. The results are equivalent, but not in agreement with the more modern theory of electron current flow.

- -

IF ANY OF YOUR ANSWERS ARE INCORRECT, GO BACK TO FRAME 26 AND TAKE THE PROGRAMMED SEQUENCE.

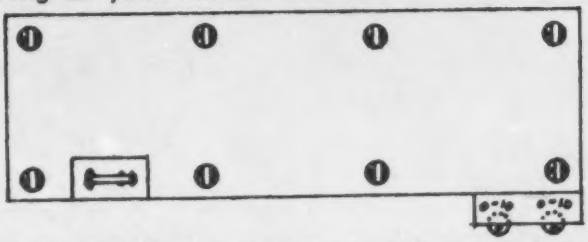
IF ALL YOUR ANSWERS ARE CORRECT GO TO THE NEXT FRAME AND FOLLOW THE DIRECTIONS GIVEN.

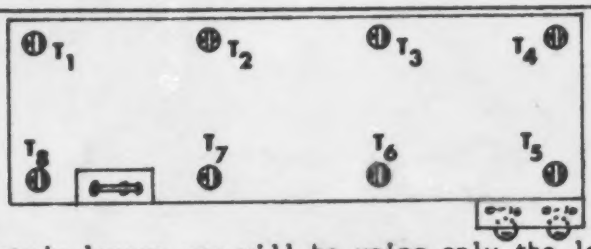
30. Now you are going to construct a simple circuit. If you do not already have these items at your carrel, go now to your learning supervisor and ask for them.

-4 dry cells
-assorted lengths of wire conductor
-vector board with some preassembled components
-simple ammeter

31. Observe the vector board before you. Notice that each spring clip is labeled with the abbreviation "T" to indicate a terminal or connection point.

    Label the terminal points on this diagram to correspond to the labeling on your vector board.





32. During this study lesson you will be using only the left half of the vector board.

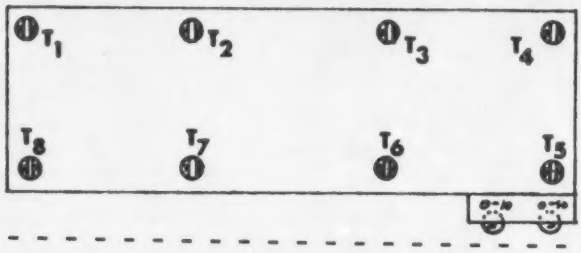
    Check the item that indicates which four connection points you will be using to construct your simple circuit.

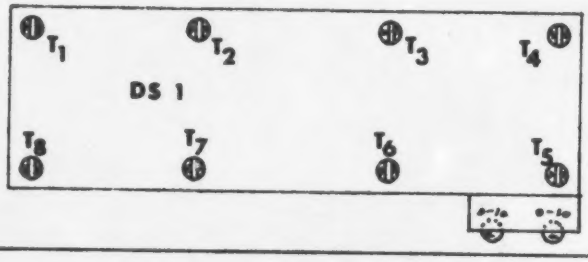
    ___ a. T1, T2, T3, T4
    ___ b. T5, T6, T7, T8
    ___ c. T1, T2, T7, T8
    ___ d. T3, T4, T5, T6

(c) T1, T2, T7, T8

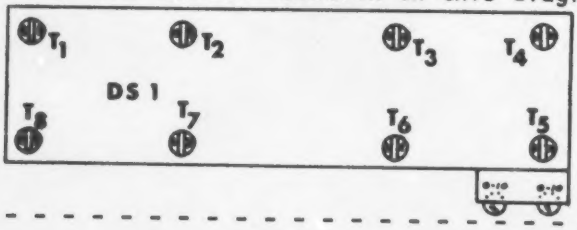
33. The vector board includes two premounted lamps. Each is labeled with the standard abbreviation for a lamp.

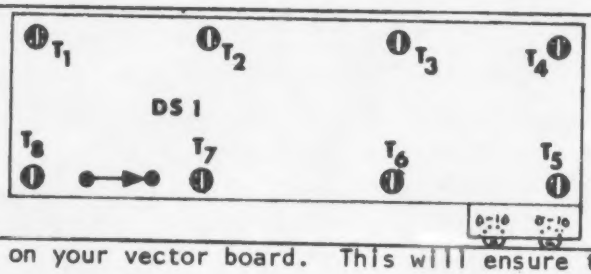
Locate the lamp that will be included in your simple circuit by writing the abbreviation for it on this diagram. Write the abbreviation on the correct location.





34. Observe the other premounted component on the part of the vector board that you will be using. Draw the schematic symbol for that component in its correct location on this diagram.





35. Open the switch on your vector board. This will ensure the circuit is:

___ a. de-energized.
___ b. energized.

(a) de-energized.

36. Wrap the bare end of a section of loose conductor around the positive terminal of the dry cell and tighten the screw. (You will use only one cell in this procedure.)

The wire will be connected around:

___ a. the outer post of the cell.
___ b. the center post of the cell.

(b) the center post of the cell

37. Take a second section of conductor and connect it to the other terminal of the cell.

You wrapped the bare end of the wire around:

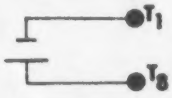
___ a. the - post.
___ b. the + post.

(a) the - post.

38. Connect the loose end of the wire from the negative cell terminal to T1.

Connect the loose end of the wire from the positive cell terminal to T8.

Check the partial schematic which correctly indicates the connections you have made.

a. ___ 

b. ___

(a)

39. Connect the two loose wires from the switch to T7 and T8 and connect the loose end of the top wire from DS1 to T2, then the other wire from DS1 to T7.

Connect a section of conductor to complete the circuit between:

___ a. T2 and T7.
___ b. T1 and T8.
___ c. T1 and T2.

(c) T1 and T2

40. Now close the switch. Did the lamp light?

_____
(yes/no)

If the lamp did not light, either return to Frame 30 or view the Sound/Slide lesson "Constructing a Simple Circuit." If the lamp still does not light, see your instructor for help.

41. Open and close the switch several times. Observe that as the metal part of the switch touches the metal contact:

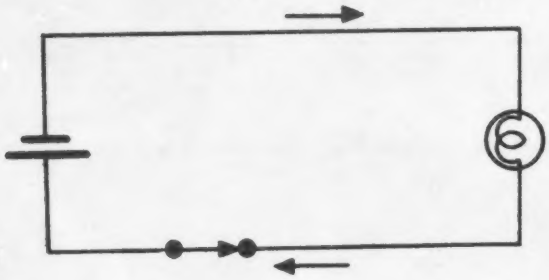
___ a. the lamp goes out.
___ b. the circuit is completed.
___ c. the circuit is opened.
___ d. the lamp lights.

(b- the circuit is completed; d- the lamp lights)

42. Open the switch and draw a schematic to represent the circuit as it appears now. Include the symbols for each circuit component. (Do not include labeled terminals.)

Your schematic should look like this:

43. Now go back and draw arrows on the schematic you drew in frame 42 to indicate the direction of current flow through the circuit when the switch is closed.



NOTE: Do NOT disassemble your simple circuit. You will be using it again in a future lesson.

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO ON TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

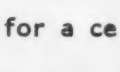
SUMMARY
LESSON III

Current Flow

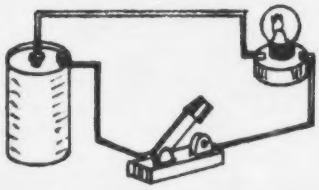
In the previous lesson you studied random drift and movement of electrons. In this lesson you will learn about the directed drift of electrons, which is the general movement of electrons in one direction through a wire. This directed drift of electrons results in a change in the location of some of the charges in the wire. Work is done when this takes place. Directed drift of electrons is called current flow. In later lessons, we will learn about the forces that produce a current flow.

For continuing current flow to take place, there must be a complete path for electrons to take. If there were only a straight piece of wire, free electrons would soon be forced to one end of the wire and no more current would flow. When a complete path exists, electrons move from the point where force is applied to them, then through the wires and back to the force through the closed loop, or circuit.

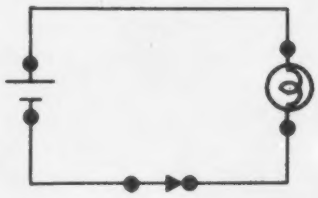
Consider a single circuit using one cell to provide force, a lamp to show when work is being done, a switch to control electron movement in the circuit, and wires to form a complete path for current flow.

An easier way to draw a circuit like this is to use schematic symbols. These are agreed upon or standard symbols that are used to represent components of electric and electronic systems. The schematic diagram for a cell is  ; for a lamp ; for a switch ; and for a wire, a simple line. ———

You can see that the path for current is not complete because of the position of the switch. This is called the open position for the switch.



A closed switch will permit current flow and is drawn like this:



The symbol for the cell (force) has one line shorter than the other. This short line is the negative terminal of the cell, and according to the electron theory of current flow, electrons will always travel from this point through a closed path and return to the positive terminal (long line)

where the force pushes them to the negative terminal again.

Electron Current Flow:

Since electrons cannot be seen, a guess was taken almost two centuries ago as to whether (+) charges or (-) charges constitute current. Unfortunately, the wrong guess was made and the positive charges were assumed to be the mobile particles. Many books still use the conventional theory of a current consisting of (+) charges moving from the positive terminal of the cell. The results are equivalent, but do not agree with the modern electron theory.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, SELECT ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

(Note: Remember there is a sound/slide presentation in this lesson.)

NOTE: ALL STUDENTS SHOULD DO THE EXERCISE INDICATED IN THE PROGRAMMED INSTRUCTION, FRAMES 30 THROUGH 43, OR THE AUDIO-VISUAL PRESENTATION, "Constructing A Simple Circuit."

BASIC ELECTRICITY AND ELECTRONICS

INDIVIDUALIZED LEARNING SYSTEM

M O D U L E O N E

L E S S O N I V

Measurement of Current

Study Booklet

OVERVIEW

LESSON IV

Measurement of Current

In this lesson you will study and learn about the following:

- -why we measure current
- -measuring is counting
- -counting electrons
- -electrons that do work
- -the coulomb
- -measurement and time
- -the ampere
- -standard abbreviations
- -powers of ten and scientific notation
- -the prefixes milli- and micro-

Each of the above topics will be discussed in the order listed. As you proceed through this lesson, observe and follow directions carefully.

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES

LESSON IV

Measurement of Current

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

Lesson Narrative
Programmed Instruction
Lesson Summary

ENRICHMENT MATERIAL:

"Powers of Ten." Programmed Instruction Booklet (BE/E).

"Scientific Notation and Powers of Ten." Programmed Instruction Booklet A-1/b-1b.

Boeke, K. Cosmic View: The Universe in 40 Jumps New York: The John Day Company, 1957.

Remember, you may study any or all of these that you feel are necessary to answer all Progress Check questions correctly. All your answers must be correct before you can go to lesson V. Remember, your instructor is available at all times for any assistance you may need.

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

NARRATIVE

LESSON IV

Measurement of Current

Why We Measure Current

We learned in the last lesson that an outside force can cause electrons to move in one direction through a circuit and that this electron movement is capable of doing work such as lighting a bulb. But we don't know how much work a given circuit is capable of performing or how much current is flowing in it. As an example, let's look again at the circuit you constructed on your vector board.

---

1. Close the switch and observe carefully the brightness (intensity) of the light.
2. Open the switch again.
3. Locate the wire that runs from the positive terminal of the dry cell to T8, and disconnect the connection at T8.
4. Now take a second dry cell, and connect the loose end of the wire you just took off of T8 to the negative terminal of the second cell.
5. Take a new piece of wire now, and connect it between the positive terminal of the second cell and T8.

You have added another cell so that the outside force has increased, and this will increase the amount of current in your circuit.

This is a schematic of your circuit as it appears now with two cells.

---

6. Now close the switch.
7. Observe the intensity of the bulb. How does the brightness of the lamp compare to its intensity in step 1?
   _____ weaker
   _____ stronger
   _____ unchanged
8. Open the switch and leave your circuit assembled.

You should have observed that the bulb glowed with greater intensity with two cells as the source. We can assume from this experiment that a greater amount of current was flowing in the circuit; however, we do not know how much. We have still not measured the amount of current in our circuit.

It is frequently important to determine the amount of current in a given piece of equipment to know if it is properly functioning and for troubleshooting.

Measuring Is Counting

To measure or quantify current, we must count electrons. Recall that current flow is the movement of electrons through a circuit. Therefore, the electrons we count must be the ones pushed through the circuit by electrical force. Electrons in a disconnected wire cannot be counted as current. In other words, the only electrons we want to count are the ones that contribute to the current flow, not the ones moving at random. Therefore, to measure current, we must count the number of electrons moving in one direction through a circuit.

Counting Electrons

At all times, there is random drift of billions and billions of free electrons within all conductors in the circuit. When an outside force is applied, it causes a general directed movement of electrons in the direction the force is pushing. This does not mean that all the free electrons instantaneously rush off in the direction they are being pushed, but that their movements will carry them along the circuit in that direction. In general, in a fraction of a second, a net average flow is set up.

Electrons That Do Work

The problem now is to find out the rate of electron movement around the circuit. Put the point of your pencil on a wire in your simple circuit. When the circuit is turned on and the push begins, billions of electrons start moving past that location in one direction. This does not mean, however, that all electrons start moving in that direction; others still move at random and may produce no detectable change in the location of any charges. In counting current, we count the net number of electrons that move in one direction and do work.

To do any work in the circuit, charges must move through it. In order to have current in a wire, electrons must continuously move around the circuit. The only electron movements that cause work to be done are the movements that are not cancelled by some movement in the opposite direction, so it is the difference, or net effect of the movements that we must measure.

The Coulomb

The number of electrons moving through the circuit is astronomical; there are so many of them they are hard to count. To make the counting easier, we count by groups instead of by single electrons. Suppose we could put electrons in containers like we do jelly beans. We could then count the number of full containers instead of the individual beans. In electricity, we refer to each container group as a coulomb (note that both container and coulomb have a "c").

Each coulomb consists of approximately 6,250,000,000,000,000,000 electrons. Therefore, when about 6,250,000,000,000,000,000 electrons pass a point on the wire, one coulomb passes that point. If twice that many electrons go past a point, two coulombs have passed.

Suppose about "6,250,000,000,000,000,000 x 3" electrons pass a point. How many coulombs pass? _____

Answer: 3 coulombs

Measurement and Time

Current flow, like the flow of water, must be measured with respect to time. A river flowing at the rate of 1,000 gallons per day is not carrying much water; a river which carries 1,000 gallons per minute is obviously carrying much more water. In the same way, a circuit conducting 10,000,000,000 electrons around it each hour has much less current flow than one which carries 10,000,000,000 electrons past a location each second.

The simple circuit you built conducts about 1,000,000,000,000,000,000 electrons (approximately 15/100 of one coulomb) per second. To help make this clear, if you place your pencil on some part of the simple circuit, when the switch is closed about 1,000,000,000,000,000,000 electrons will go past your pencil point in the time it takes to snap your fingers! So not only must we know how many coulombs go past the point, we must know how fast they go past a certain location. When we talk of how many, we talk of coulombs. When we talk of how many coulombs per second, we talk of amperes.

The Ampere

An ampere is an electron movement of one coulomb (about 6,250,000,000,000,000,000 electrons) per second past a certain location in a circuit. In other words, if one coulomb, or group

of electrons passes a point in a circuit in one second, one ampere of current is flowing. Two coulombs flowing through a wire in one second, then, would be two amperes.

How many amperes are flowing if one coulomb moves past a point in half a second?

Answer: 2 amperes

Standard Abbreviations

There are several ways to make writing and talking about current flow easier. One way is to use standard abbreviations for the things we work with; for example, the letter "I" is used to represent current flow. Current flow = I. If you want to write "the current flow in that circuit is three amperes," you may use "I = 3 amperes" and say the same thing. Another abbreviation is the letter "A" (either upper or lower case) which stands for amperes. This allows you to write the same statement even more briefly as "I = 3a." These symbols simplify writing and are used in almost every country that uses our alphabet.

Using standard symbols, write "the current flow is equal to two amperes."

Answer: I = 2a

The relationship between current, charge and time can be stated mathematically as $I = \frac{Q}{T}$ where I represents current in amperes, Q is charge in coulombs, and T is time in seconds.

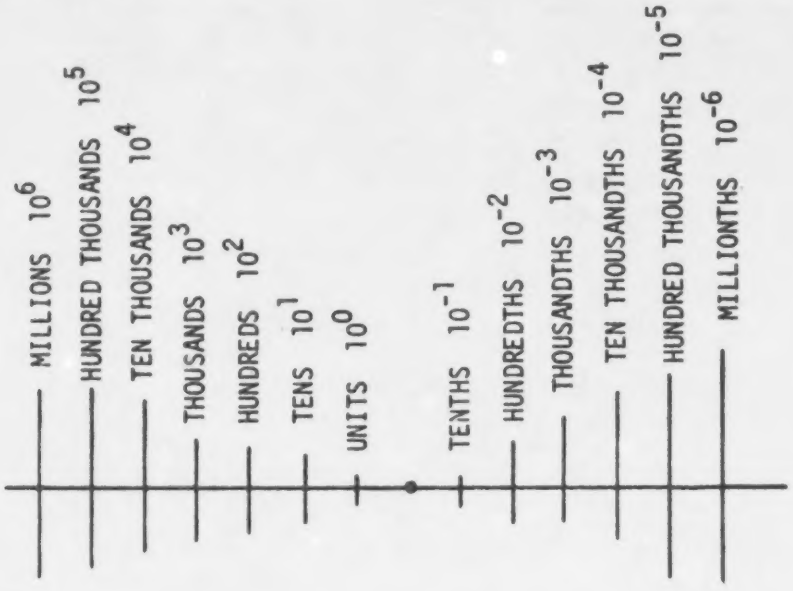
One convenient way of dealing with very large (or very small) numbers such as the number of electrons in a coulomb of charge is to employ powers of ten. This system is based on the idea that by moving the decimal point one place to the right or left we change a number's value by a factor of ten. For example, if we start with a number such 1235. and move the decimal point one place to the left (123.5), we have effectively divided the original number by ten. If, on the other hand, the decimal were moved to the right (12350.), we have effectively multiplied by ten.

Powers of Ten and Scientific Notation

Let's see how we use this "powers of ten" idea to count electrons.

Look at the number one million (1,000,000). Although not shown, you know there is a decimal point after the sixth zero (1,000,000.), and that we can add zeroes to the right of the decimal without changing the value, like this (1,000,000.00). You also know that one hundred thousand times ten equals one million ($100,000 \times 10 = 1,000,000$). Then ten thousand times ten times ten equals one million ($10,000 \times 10 \times 10 = 1,000,000$) and ten times ten equals ten squared ($10 \times 10 = 10^2$), so ten thousand times ten squared equals one million ($10,000 \times 10^2 = 1,000,000$). This argument can be carried to the point that one times ten times ten times ten times ten times ten equals one million ($1 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 = 1,000,000$). In each step we have moved the decimal point to the left one place. We could easily write $3 \times 10^6 = 3,000,000$ or $3.45 \times 10^6 = 3,450,000$. When we are working with numbers like 6,250,000,000,000,000,000, then 6.25×10^{18} electrons make one coulomb, it seems well worth the little trouble it takes to learn this system.

The following chart may help you to use powers of ten. It shows our decimal number system and the power to ten which corresponds to each place. Study it!



Write 5,000,000 as a power of ter using ten to the sixth power. _____

Answer: 5×10^6

You can use this method to express very small numbers also. In this case, you must move the decimal point to the right and use a negative power of ten. One one-thousandth (.001) becomes one times ten to the minus third (1×10^{-3}).

Write (.0000028) as a number times ten to negative sixth power. _____

Answer: 2.8×10^{-6}

Scientific Notation makes use of powers of ten to write numbers in a standard way. In scientific notation, the decimal point is always placed behind the first digit of a number and the appropriate power of ten is used. For example, the number of electrons in a coulomb is written 6.25×10^{18} rather than 62.5×10^{17} or $.625 \times 10^{19}$.

Milli- and Micro-amperes

A useful way of working with current (and other) measurements when the values are fractions of an ampere is to use the metric prefixes milli- and micro-. Milli- means thousandths (.001), and micro- means millionths (.000001). You can see this fits right in with the powers of ten (milli = 10^{-3} and micro = 10^{-6}). One milliampere is, therefore, equal to one one-thousandth of an ampere or 10^{-3} amperes.

Writing these in the short way, the small letter "m" is used for milli- and the Greek letter mu "μ" is used for micro-. To write "the current flow is 30 microamperes," you could write either "$I = 30 \times 10^{-6}$ a" or "I = 30 μa." If the current were 4 milliamperes, you could write "I = 4 ma" or "$I = 4 \times 10^{-3}$ a."

Express:

a. 0.006 a in ma _____.
b. 0.00005 a in μa _____.
c. 0.002 ma in μa _____.

Answer: a. 6 ma
b. 50 μa
c. 2 μa

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION

LESSON IV

Measurement of Current

TEST FRAMES ARE 12, 22, 42, and 53. AS BEFORE, GO FIRST TO TEST FRAME 12 AND SEE IF YOU CAN ANSWER ALL THE QUESTIONS THERE. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

1. Current was described as the:

___ a. directed drift of protons.
___ b. random drift of neutrons.
___ c. directed drift of electrons.
___ d. random drift of electrons.

- -

(c) directed drift of electrons

2. Current flow results from the directed movement of charges caused by the application of a:

___ a. force inside the atom.
___ b. force external to the atom.

- -

(b) force external to the atom

3. The amount of external force is one factor which determines the amount of current flow. If the force being applied is increased, there will be a corresponding increase in current.

What will happen if the amount of force is decreased?

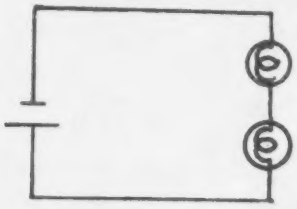
___ a. Current will remain the same.
___ b. Current will decrease.
___ c. Current will increase.

- -

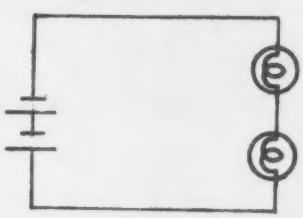
(b) Current will decrease

4. Which circuit will have the greatest current flow? (Assume that the cells are all the same kind and that the lamps are identical.)

a.



b.



(b)

5. Which of the following will have less current flow? (Assume that the cells are of the same type.)

___ a. a circuit with six cells supplying the outside force.
___ b. A circuit with three cells supplying the outside force.

(b) a circuit with three cells supplying the outside force

6. Since the directed drift of electrons constitutes current flow, you can infer that the amount of current can be determined by counting the number of _____ moving past a location each second.

(electrons)

7. This counting of directed electrons is a method of current measurement.

Current measurement is always used to determine the:

___ a. amount of electrons in a wire.
___ b. amount of current flow.
___ c. amount of outside force being applied.

(b) amount of current flow

8. When measuring current flow, time (t) must also be taken into consideration.

   Which would be the highest current flow?

   ___ a. 36 electrons passing per hour.
   ___ b. 60 electrons passing per minute.
   ___ c. 10 electrons passing per second.

(c) 10 electrons passing per second

9. Since electrons are moving throughout the circuit, electrons can only be measured as they pass a given _____ in the conductor.

(point or location)

10. When measuring current, both the number of electrons passing a given location and _____ must be considered.

(time)

11. Which correctly describes current measurement?

   ___ a. determining the number of electrons passing a given location in a conductor within a specified time
   ___ b. counting the total number of electrons moving throughout a circuit
   ___ c. measuring the number of electrons between two or more points in a conductor
   ___ d. determining the magnitude of the random drift

(a) determining the number of electrons passing a given location in a conductor within a specified time

12. Check each true statement.

___ a. Current flow in a disconnected wire cannot be measured.
___ b. Measurement of current is a measure of the number of electrons in a wire.
___ c. Measurement of current is a measure of the number of electrons passing a given point per unit time.

- -

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 12

a - current flow in a disconnected wire cannot be measured
c - measurement of current is a measure of the number of electrons passing a given point per unit time

---

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 22. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 12 AGAIN.

---

13. Because of the astronomical number of electrons moving in a wire, electrons are best counted in large groups, such as coulombs. A coulomb is the unit of measurement for electrical charge and contains about 6,250,000,000,000,000,000 electrons.

    If this number is multiplied by 2, how many coulombs would this be? _____

---

(2)

---

14. The symbol for charge is "Q." We have seen one unit of charge is the coulomb.

    How many coulombs are there in the following problems?

    ___ a. 6,250,000,000,000,000,000 electrons

    ___ b. $\overline{6,250,000,000,000,000,000}$ electrons $\times 3$

    ___ c. $\overline{6,250,000,000,000,000,000}$ electrons $\times 5$

    $\overline{\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad}\times 7$

(a. 3 coulombs; b. 5 coulombs; c. 7 coulombs)

15. The amount of current flow in a circuit is determined by dividing the amount of charge (Q) by the amount of time (t) required for these charges to pass a given point.

Which formula would be used to determine current flow?

___ a. $Q = \frac{t}{\text{current}}$

___ b. $\text{current} = \frac{t}{Q}$

___ c. $t = \frac{\text{current}}{Q}$

___ d. $\text{current} = \frac{Q}{t}$

- -

(d) $\text{current} = \frac{Q}{t}$

16. The unit of measurement for current flow is the ampere (abbreviated amp or a). The ampere is defined as one coulomb of charge passing a given point in one second.

Two coulombs passing a given point in 4 seconds is how many amperes of current?

___ a. 8 amps
___ b. 0.5 amps
___ c. 2 amps
___ d. 4 amps

- -

(b) 0.5 amps

17. Using the mathematical formula, $I = \frac{Q}{t}$, determine how many units of current flow there would be if 3 coulombs pass a given point in one second. _____

___ a. 1/3 ampere
___ b. 3 amperes
___ c. 9 amperes

- -

(b) 3 amperes (NOTE: your answer is incomplete if you do not include the unit [amperes])

18. Determine the current flow in each of the following problems.

___ a. Q = 10 coulombs
t = 5 seconds

___ b. Q = 12 coulombs
t = 3 seconds

___ c. Q = 14 coulombs
t = 7 seconds

___ d. Q = 20 coulombs
t = 40 seconds

- -

(a. 2 amps.; b. 4 amps.; c. 2 amps.; d. .5 amps.)

19. "I" is the letter symbol for the movement of coulombs, therefore I = Q/t. Which of the following is represented by I?

___ a. coulomb
___ b. ampere
___ c. current

- -

(c) current

20. Match the letter symbol to its appropriate electrical terms.

___ 1.	charge	a. a
___ 2.	ampere	b. I
___ 3.	current	c. Q
___ 4.	amp	

- -

(1. c-Q; 2. a-a; 3. b-I; 4. a-a)

21. Match the statements to their equivalent mathematical expression.

___ 1.	I = 6 a	a. The current flow is 6 amperes.
___ 2.	I = 5 a	b. Four amps of current are flowing.
___ 3.	I = 4 a	c. Current flow in the circuit is 5 amperes.

- -

(1. a-the current flow is 6 amperes; 2. c-current flow in the circuit is 5 amperes; 3. b-four amps of current are flowing)

22. Convert the following statements to their equivalent mathematical expressions.

_____ a. The current flow is equal to 10 amperes.
_____ b. Eight amperes of current are flowing.
_____ c. The current is 3 amps.
_____ d. The current (in any unit) is charge per unit time.

- -

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 22

a. I = 10a
b. I = 8a
c. I = 3a
d. I = Q/t

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 42. OTHERWISE, GO BACK TO FRAME 13 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 22 AGAIN.

23. When solving mathematical expressions, it can be very cumbersome to manipulate figures such as 6,250,000,000,000,000,000. For this and other reasons, a simplified, abbreviated method called scientific notation is used.

Scientific notation is:

___ a. a method of simplifying very large numbers.
___ b. a form of abbreviation.
___ c. used to make mathematical computations easier.
___ d. (all of the above)

(d) all of the above

24. Below are two examples of numbers converted to scientific notation:

$$100 = 1 \times 10^2$$
$$2000 = 2 \times 10^3$$

The number written above and to the right of the number 10 is called an exponent.

Which numbers below have indicated exponents?

___ a. 10^4
___ b. 10_5
___ c. 10×10
___ d. 5×10^3

(a. 10^4; d. 5×10^3)

25. In the expression 10^2, the exponent indicates that 10 is to be multiplied by itself.

10^4 means that:

___ a. 10 is used as a factor 4 times.
___ b. four tens must be multiplied together.
___ c. 10_4 is equal to 10,000.
___ d. 10^4 is equal to 1,000.

(a. 10 must be multiplied by itself 4 times; b. four tens must be multiplied together; c. 10^4 is equal to 10,000)

26. A number which has an exponent is said to be raised to a power.

Which numbers below are to be raised to a power?

___ a. 100^{10}
___ b. 10^{-5}
___ c. 10 x 5
___ d. 10_5

(a) 100^{10}; b. 10^{-5}

27. The number below and to the left of the exponent is called a base number.

In the expression 10^6, which is the base number? _____

---

(10)

28. The system of scientific notation using powers of ten is possible because of our decimal or base 10 numbering system.

Our base 10 numbering system makes possible a system of scientific notation utilizing _____.

(Powers of ten)

29. Because of our base 10 numbering system, we can express any number as a number times some power of ten without changing the numerical value.

$$128.2 = 12.82 \times 10^{1} = 1.282 \times 10^{2} = 0.1282 \times 10^{3}$$

Each time the decimal point is moved one place to the left, it's the same as _____ the original number
multiplying/dividing
by _____. This is indicated by increasing the exponent by 1 each time.

(dividing; 10)

30. Indicate the proper exponent.

$3000 = 30 \times 10^{__} = .3 \times 10^{__}$

30×10^{2}, 0.3×10^{4}

31. Scientific notation provides a convenient way of dealing with very large or very small numbers. Any number may be written in scientific notation by expressing it as a number equal to or larger than one but less than ten; this number multiplied by ten with the appropriate exponent.

Which are examples of numbers expressed in scientific notation?

___ a. 6,250,000,000,000,000,000

___ b. 1.54×10^{2}

___ c. 10×10^{2}

___ d. 25×10

___ e. 8×10^{4}

(b. 1.54×10^{2}; e. 8×10^{4})

32. To convert a number greater than one to scientific notation, the first step is to locate the decimal point.

    Example: start with 256; place a decimal to the right of the 6, namely 256.

    Given: 5324 - where will you place the decimal?

- -

(5324.)

33. The second step is to move the decimal point to the LEFT until the only digit to the LEFT of the decimal is a number equal to or greater than one but less than ten.

    Example: 256 - Step One 256. Step Two 2.56

    Given: 4732 - Step one _____ Step Two _____

- -

(4732. 4.732)

34. The third step is to count the number of places the decimal point was moved to the LEFT. This will be the correct POSITIVE exponent for scientific notation of numbers equal to or greater than one.

    Example: 256 - Step One: 256. Step Two: 2.56
    Step Three: 2.56×10^{2}

    Given: 5374 - Step One: _____ Step Two: _____
    Step Three: _____

- -

(5374. 5.374 5.374×10^{3})

35. If the number you are converting to scientific notation already has a decimal (e.g., 146.5), omit step one and proceed.

    Example: 146.5 Step One: (skip) Step Two: 1.465
    Step Three: 1.465×10^{2}

    Given: 39.4 Convert to scientific notation

- -

(3.94×10^{1})

36. Recall that a coulomb equals about 6,250,000,000,000,000,000 electrons.

Place a check in front of the answer which correctly expresses a coulomb in scientific notation.

___ a. 62.5×10^{18} electrons

___ b. 6.25×10^{24} electrons

___ c. $.625 \times 10^{24}$ electrons

___ d. 6.25×10^{18} electrons

(d) 6.25×10^{18} electrons

37. Express the following numbers in scientific notation.

___ a. 2745
___ b. 263
___ c. 24.5
___ d. 5,000

(a. 2.745×10^{3}; b. 2.63×10^{2}; c. 2.45×10^{1}; d. 5×10^{3})

38. To convert numbers less than one to scientific notation, move the decimal point to the RIGHT until there is just one digit to the LEFT of the decimal point. Count the number of places the decimal point was moved. This will be the correct NEGATIVE exponent for scientific notation for numbers less than one.

Example: $.00492 = 4.92 \times 10^{-3}$

Given: .0005 = _____

(5×10^{-4})

39. Convert the following numbers to scientific notation.

.157 _____
.0054 _____
.000032 _____

(1.57×10^{-1} 5.4×10^{-3} 3.2×10^{-5})

40. Okay, let's run through it again!

To convert decimal fractions to scientific notation:

1. Move decimal point to the RIGHT until there is a single digit number from 1 to 9 to the LEFT of the decimal point.

   Example: .017 - Move the decimal to RIGHT - 1.7

2. Count the number of places the decimal was moved to the RIGHT.

   Example: .017 - Step One: 1.7 Step Two: moved 2 places

3. This is the correct NEGATIVE power of ten.

   Example: .017 - Step One: 1.7 Step Two: moved 2 places
   Step Three: 1.7×10^{-2}

Express the following in powers of ten:

a. .000014 = _____
b. .143 = _____
c. .027 = _____

(a. 1.4×10^{-5}; b. 1.43×10^{-1}; c. 2.7×10^{-2})

41. To convert any number from scientific notation, simply move the decimal point in the appropriate direction the number of places indicated by the power of 10.

For example: $6.75 \times 10^{4} = 67{,}500$ (decimal moves 4 places right)
$6.32 \times 10^{-3} = .00632$ (decimal moves 3 places left)

Convert from scientific notation.

_____ a. 6.75×10^{-4}
_____ b. 3.28×10^{2}
_____ c. 4.71×10^{-1}
_____ d. 6.28×10^{3}

(a. .000675; b. 328; c. .471; d. 6,280)

42. Convert the following numbers as indicated.

To Scientific Notation		To Decimal Numbers	
_____	a. 120	_____	d. 10^{-1}
_____	b. 0.0125	_____	e. 10^{5}
_____	c. 138,000	_____	f. 10^{4}

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 42

a. 1.2×10^{2}

b. 1.25×10^{-2}

c. 1.38×10^{5}

d. .1

e. 100,000

f. 10,000

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO FRAME 53. OTHERWISE, GO BACK TO FRAME 23 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 42 AGAIN.

43. Another useful system of abbreviations is the use of metric prefixes. Below is a table which lists two prefixes commonly used in measurement. The table also shows abbreviation, expression in powers of ten, and values.

Complete and refer to this table in answering frames 48 to 51.

PREFIX	ABBREVIATION	POWER OF TEN	VALUE
milli	m	10^{-3}	( )
micro	μ	10^{-6}	millionths or 1/1,000,000

(thousandths or 1/1000)

44. Which of the following is equal to a milliamp?

___ a. 1000 amps
___ b. 1/1000 amp
___ c. 1×10^{3} amps
___ d. 1×10^{-3} amps

(b. 1/1000 amp; d. 1×10^{-3} amps)

45. Write one microamp as a fraction and in scientific notation.

_____ _____

(1/1,000,000 amp 1×10^{-6} amp)

46. Match.

___ 1. 1×10^{-6}
___ 2. 1/1000 amp
___ 3. 1/1,000,000 amp
___ 4. 1×10^{-3} amp

a. milliamp
b. microamp

(1. b-microamp; 2. a-milliamp; 3. b-microamp; 4. a-milliamp)

47. Recall that ampere is abbreviated a.

How would milliamp be abbreviated? ____

(ma)

48. Change the following to ma.

a. $I = 6 \times 10^{-3}$ amps _____ ma

b. $I = 3.5 \times 10^{-3}$ amps _____ ma

c. I = .042 amps _____ ma

(a. I = 6ma; b. I = 3.5ma; c. I = 42ma)

49. The Greek letter μ (mu) is used to indicate the prefix micro-.

How would microamp be abbreviated? _____

(μa or μA)

50. Conversions can be handled easily by using powers of ten.
For example: it is desired to change .023 ma to μa.
First: Write .023 ma as a power of 10 = $.023 \times 10^{-3}$a

Second: Move the decimal point to the right 3 places to increase the power of 10 to 10^{-6} = 23×10^{-6}

Third: Write the number using the μ prefix = 23 μa

Another example: .1a to ma (1) $.1 \times 10^{0}$ (2) 100×10^{-3} (3) 100 ma

Make the following conversions

a. .006a = _____ ma
b. 200μa = _____ ma
c. .062ma = _____ a
d. 24ma = _____ μa

(a. 6ma; b. .2ma; c. .000062a; d. 24,000μa (24×10^{3}μa)

51. Express as indicated.

a. .006a = _____ ma
b. .00005a = _____ μa
c. .002ma = _____ μa

(a. 6ma; b. 50μa; c. 2μa)

52. Convert the following expressions as indicated, writing your answers as decimals.

TO AMPS		TO MILLIAMPS	
___	a. 100 milliamps	___	d. 0.1 amps
___	b. 1000 milliamps	___	e. 1/1,000 amps
___	c. 10 milliamps	___	f. 0.01 amps

(a - .1a; b - 1a; c - 0.01a; d - 100ma; e - 1ma; f - 10ma)

53. Using scientific notation

Convert to a.		Convert to μa.	
____	a. 10ma	____	e. .005a
____	b. 5ma	____	f. .010a
____	c. 4μa	____	g. .000002a
____	d. 30μa	____	h. .000020a

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 53

a. 1×10^{-2}a or 10^{-2}a

b. 5×10^{-3}a

c. 4×10^{-6}a

d. 3×10^{-5}a

e. 5×10^{3}μa

f. 1×10^{4}μa or 10^{4}μa

g. 2×10^{0}μa

h. 2×10μa or 2×10^{1}μa

- -

IF ANY OF YOUR ANSWERS IS INCORRECT, GO BACK TO FRAME 43 AND TAKE THE PROGRAMMED SEQUENCE.

IF YOUR ANSWERS ARE CORRECT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO ON TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

SUMMARY
LESSON IV

Measurement of Current

All measurement is some form of counting or quantifying, and measuring current flow is no exception. Since current flow is the movement of electrons, we count the number of free electrons (directed movement) passing through the circuit per unit time to measure current.

Because the amount of charge carried by one electron is minutely small, an extremely large number of electrons must move around the circuit to do a significant amount of work. To simplify the counting, a larger unit of charge called the coulomb is used. One coulomb has about 6.25×10^{18} electrons in it. Think of it: 10^{18} is a million, million, million!

The other factor to be considered in measuring current flow was seen to be time. The more electrons moving through a wire in one second, the greater is the current flow.

The basic unit of current flow is the ampere. One ampere of current flows when one coulomb of charge (6.25×10^{18} electrons) passes any position in the circuit in each second.

To simplify writing and talking about current flow, several shortcuts are used. One is to abbreviate ampere by the letter A (either capital or small) in writing. In speaking, an ampere will usually be called an amp. Another abbreviation used is the letter "I" which stands for current flow. To write "the current flow is three amperes" using this system, you would write "I = 3a"; in speaking, you would say "I (or the current) equals three amps."

The relationship between current, time, and charge can be given mathematically as $I = \frac{Q}{T}$ where I is the current in amps, T is the time in seconds, and Q is the charge in coulombs.

The last shortcut to simplify working with current is the use of the metric prefixes milli- and micro-. One milliampere is one one-thousandth of an ampere and one microampere is one one-millionth of an ampere. These are abbreviated by the small letter "m" for milli ("ma" means milliampere) and the Greek letter mu "μ" for micro ("μa" for microamperes).

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

BASIC ELECTRICITY AND ELECTRONICS

INDIVIDUALIZED LEARNING SYSTEM

M O D U L E O N E

L E S S O N V

The Ammeter

Study Booklet

OVERVIEW

LESSON V

The Ammeter

In this lesson you will study and learn about the following:

- -why the ammeter
- -how an ammeter works
- -meter tolerances
- -the practical use of the ammeter

Each of the above topics will be discussed in the order listed. As you proceed through this lesson, observe and follow directions carefully.

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON V

The Ammeter

To learn the material in this lesson, you have the option of choosing, according to your experience and your preferences, any or all of the following:

STUDY BOOKLET:

Lesson Narrative
Programmed Instruction
Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-1a "Basic Electricity, Direct Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

AUDIO-VISUAL:

Sound/slide presentation, "The Ammeter."

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME. UPON COMPLETION OF THIS LESSON, YOU SHOULD ASK YOUR INSTRUCTOR FOR THE MODULE TEST COVERING ALL THE LESSONS IN THIS BOOKLET. YOU MAY REVIEW PREVIOUS LESSONS IF YOU WISH.

NARRATIVE

LESSON V

The Ammeter

Why the Ammeter

We cannot see or feel either electrons or coulombs to count them, so we need some device to detect them for us. The lamp we used in lesson IV gives some indication of current flow, but it has two major drawbacks:

1. It does not measure current in any units which can be easily recorded and compared to measurements made at other times or places.

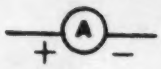
2. It is useful over a very small range of current flow only. If the current is too small, the lamp will not glow; if the current is too large, the lamp will burn out.

To overcome the first objection, we need a device that can tell us how many amperes (coulombs of electrons per second) are moving through the circuit. A special meter designed to do this is called an ammeter. The name is derived from the ampere, but notice that the "p" is dropped and only the first two letters of ampere are used in spelling ammeter. The design of the ammeter takes care of the second drawback also, making it a useful measuring tool for you.

How an Ammeter Works

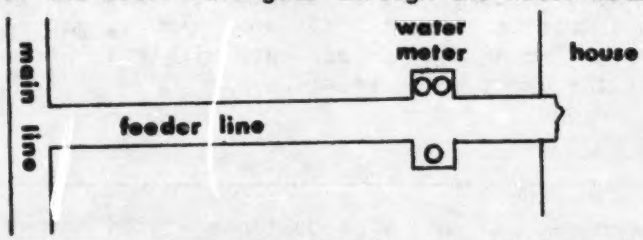
An ammeter indicates the amount of current flowing through it by the position of a pointer in front of a calibrated dial face. The movement of the pointer is proportional to the rate of electron movement through the meter, that is, how much charge moves through it each second.

The schematic symbol for an ammeter is:

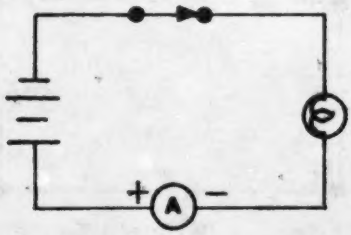


How To Use An Ammeter

The ammeter is in many ways similar to the water meter which measures how much water is used in your house. Both meters must be connected so that the currents (water or electric) you want to measure flow through them. All the water going into your home from the water main goes through the water meter like this:



In the same way, an ammeter must be connected so that all the electric current to be measured goes through the ammeter like this:



This kind of connection is called a series circuit, which simply means that everything is connected in a straight line (one conducting path). The cell you added in Lesson IV was in series with the rest of the circuit components.

Hooking Up An Ammeter

To connect the ammeter in series, you must first de-energize (take away the outside force from) the circuit. The second step is to open (cut or break) the circuit where you are going to insert the ammeter.

Now connect the positive (+) terminal of the ammeter to the wire which leads toward the positive terminal of the cell, and the negative (-) ammeter terminal to the wire which leads toward the negative connector of the cell. The process of connecting positive to positive and negative to negative is called observing polarity, and it is necessary because the meter will read current in one direction only. Connecting the meter backward will make it try to read in reverse and may bend or break the pointer.

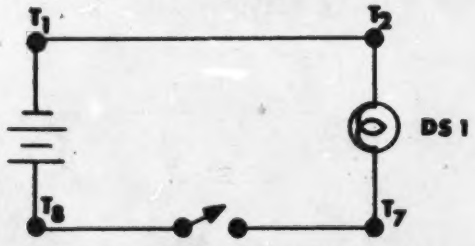
The red meter lead should be inserted in the red ammeter jack and the black lead in the black ammeter jack on top of the ammeter.

Meter Tolerances

With respect to meter readings, it should be noted that measurements of the same circuit taken by several different meters could vary slightly. This is because some of the circuit energy is used to operate the meter and no two meters are exactly alike. Also, because of differences in construction and energy losses within the meter, readings must be thought of as approximate, not exact, readings. Normally, a meter will be accurate within a $\pm 5\%$ tolerance range of the exact measurement.

Experiment #1 - Using an Ammeter

Now using the procedures and safety precautions listed below, you will measure the current flow through the circuit constructed in Lesson IV:



1. Draw a simple ammeter from the Resource Center.

(Note: Care must be taken in the selection of the meter. The current flowing in the circuit must not exceed the range of the meter used. For this experiment you can assume that the meter provided has a high enough range to handle the circuit current. However, in following experiments you will be required to determine this for yourself.)

2. Attach the alligator clips to the meter test leads (red to red, black to black).

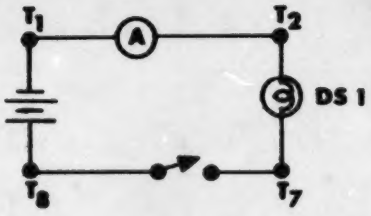
3. Ensure your circuit is de-energized. The switch should be in the open position. (AS A MATTER OF PERSONAL SAFETY NEVER ATTEMPT TO CONNECT A METER IN AN ENERGIZED CIRCUIT.)

4. Open the circuit by removing the wire between T1 and T2 (the ammeter will be inserted between these points to complete the circuit).

5. Attach the meter leads to T1 and T2 observing polarity (black lead to T1, red lead to T2).

If proper polarity is not observed the needle will attempt to deflect to the left. This will result in damage to the meter.

The circuit should now look like this:



6. Close the switch and observe the meter reading. Look directly at the meter face from the front; do not make the reading when looking at the meter from an angle.

7. Record the reading. _____

8. De-energize the circuit.

Your reading should be approximately 0.24 amps. Recall what we said about meter tolerances.

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1. Now disconnect the second cell by unhooking the wire from that cell to T8, and the wire from the + terminal of cell one to the - terminal of cell two.

2. Reconnect cell one as the only source for the circuit by connecting wire from positive terminal to T8. (Wire from negative terminal should still be connected to T1.)

3. Connect probes of ammeter at T1 and T2, observing correct polarity.

4. Close switch and record meter reading. _____

5. Open switch.

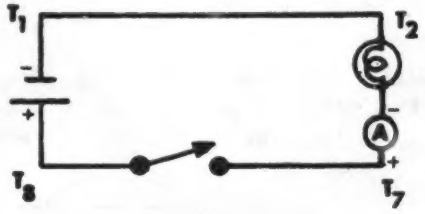
6. Disconnect meter clips.

You should have recorded approximately 0.16 amps.

Recall that the ammeter must be connected in the circuit so that it becomes a part of the circuit and completes the path for current flow. In a simple circuit where all components are in series one right after the other, the ammeter reading will be the same at any place in the circuit. To prove this, let's disconnect the lamp from T7 and connect the ammeter between T7 and the lead you just removed.

1. Connect a wire between points T1 and T2.

2. With switch in open position, connect red meter clip to T7 and black meter clip to the side of the lamp closest to T7 to observe polarity.



3. Close the switch.

4. Record the ammeter reading. _____

Again you should have an approximate reading of 0.16 amps -- the same reading you got at another point in the series circuit.

NOW YOU MAY EITHER TAKE THE PROGRESS CHECK OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, YOU HAVE MASTERED THE MATERIAL AND ARE READY TO TAKE THE MODULE TEST. SEE YOUR INSTRUCTOR.

IF YOU DECIDE NOT TO TAKE THE PROGRESS CHECK AT THIS TIME, OR IF YOU MISSED ONE OR MORE QUESTIONS, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU HAVE ANSWERED ALL THE PROGRESS CHECK ANSWERS CORRECTLY. THEN SEE YOUR INSTRUCTOR AND ASK TO TAKE THE MODULE TEST.

PROGRAMMED INSTRUCTION

LESSON V

The Ammeter

TEST FRAMES ARE 13, 21, 27, and 28. AS BEFORE, GO FIRST TO TEST FRAME 13 AND SEE IF YOU CAN ANSWER ALL THE QUESTIONS THERE. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

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1. Recall that current flow in a wire is the movement of sub-microscopic particles called:

___ a. protons.
___ b. neutrons.
___ c. electrons.

- -

(c) electrons

2. Amperage or the amount of current is partly determined by:

___ a. counting the number of electrons passing a given point per second.
___ b. measuring the velocity of electrons.
___ c. measuring the distance a coulomb travels in one second.

- -

(a) counting the number of electrons passing a given point per second

3. Since electrons cannot be seen, a special measuring device must be used to determine amperage.

The name of a device used to measure current is an ammeter, or _____ meter.

___ a. voltage
___ b. amperage
___ c. resistance

- -

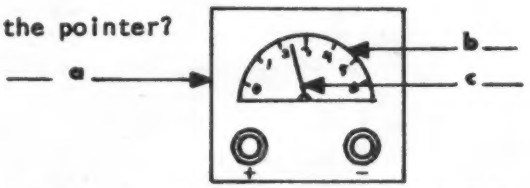
(b) amperage

4. An ammeter is used to measure _____.

(current or amperage)

5. The ammeter indicates the amount of current flow by the position of a pointer in front of the meter dial.

Which lettered arrow identifies the pointer?



(c) pointer

6. Refer to the illustration in frame 5. The amount of current flowing is _____.

(approximately 2.3 amps)

NOTE: No two meters are exactly alike and therefore their readings will differ slightly. In general, the equipment will give a reading within a ±5% tolerance range.

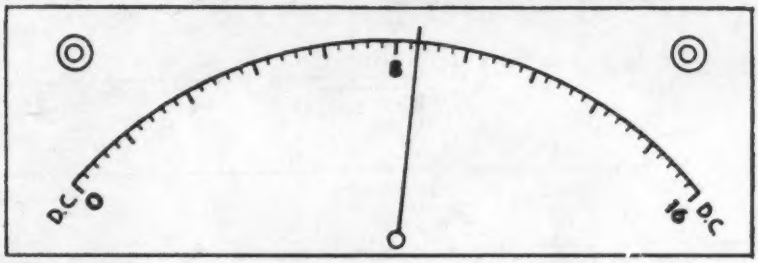
7. The position of the pointer is determined by the amount of current flow through the meter: the greater the current, the farther the pointer will move, and the higher the meter will read.

Select the current flow which will give the greatest movement of the pointer.

___ a. 3 amps
___ b. 2 amps
___ c. 4 amps
___ d. 1 amp

(c) 4 amps

8. Each meter has a maximum current that it can measure. This is indicated by the highest number indicated on its dial.



The maximum safe current to pass through the above meter is:

___ a. 8 amps
___ b. 16 ma
___ c. 16 mu
___ d. 16 amps

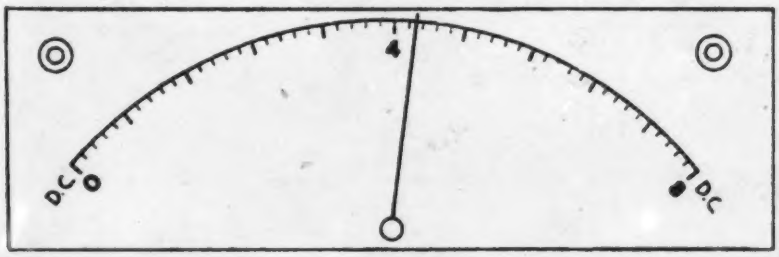
(d) 16 amps

9. Now repeat this question with a meter available to you from the resource center.

The maximum limit of your meter is _____.

(1 amp)

10.



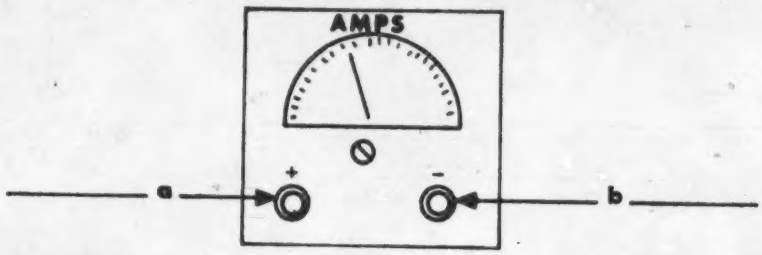
The maximum safe current for the meter illustrated above is:

___ a. 8 μa
___ b. 8 ma
___ c. 8 amps
___ d. 5 amps

(c) 8 amps

11. The ammeter also contains terminals to allow it to be placed into the circuit. The positive terminal is colored red and the negative terminal is black.

Label the terminals according to their correct color.



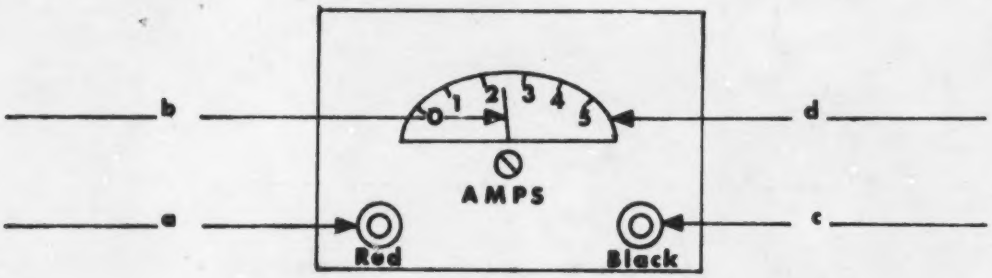
(a - red; b - black)

12. Match:

___	1. +	a.	negative terminal
___	2. -	b.	positive terminal
___	3. red		
___	4. black		

(1. b-positive terminal; 2. a-negative terminal; 3. b-positive terminal; 4. a-negative terminal)

13. Label the parts of the meter shown in the illustration below.



(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 13

a. positive terminal

b. pointer

c. negative terminal

d. meter dial

- -

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 21. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 13 AGAIN.

14. The leads, or wires, used with ammeters are usually the same color as the terminals of the meter.

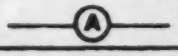
Select the correct lead and terminal combinations.

___ a. red lead, black terminal, positive
___ b. red lead, red terminal, positive
___ c. black lead, black terminal, negative
___ d. black lead, red terminal, negative

(b- red lead, red terminal, positive; c- black lead, black terminal, negative)

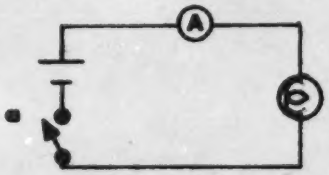
15. To simplify schematics, the ammeter is shown as a circle with the letter "A" inside it.

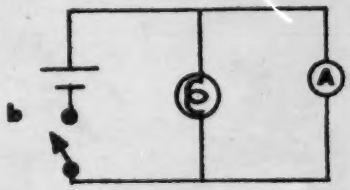
Draw the schematic symbol for an ammeter.

()

16. The ammeter must be connected in the circuit so the current to be measured flows through the ammeter, and all the circuit components. This is known as a series connection.

Select the illustration showing the ammeter correctly connected into the circuit.

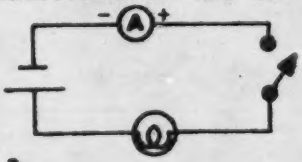




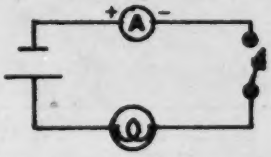
(a)

17. The polarity (+ to + and - to -) of the meter and circuit must be observed when connecting an ammeter into the circuit.

Select the schematic which has the ammeter correctly installed.



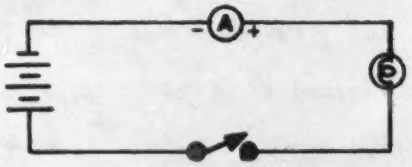
a. ___



b. ___

(a)

18. The ammeter must be connected in series with the circuit whose current you are measuring. Remember - in series means in a line. So here is how the meter would be connected into a circuit.



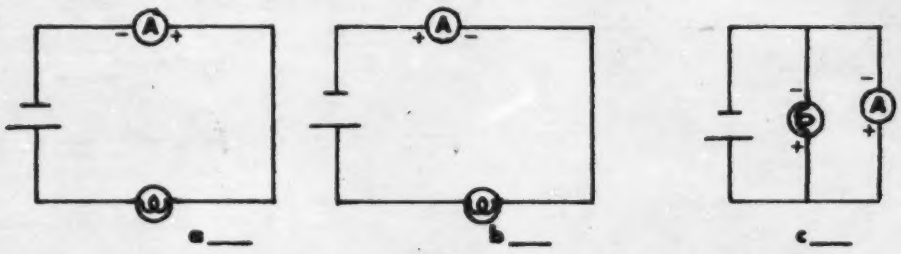
As you can see, polarity was observed by connecting the _____ lead to the negative terminal of the cell and the _____ lead to a more positive point thus connecting the ammeter in _____.

(negative - positive - series)

19. If the ammeter were to be connected across any component of the circuit, it would probably be damaged by excessive current. ALWAYS CONNECT THE AMMETER IN _____.

(series)

20. Check the schematic which shows the ammeter correctly installed.



(a; b is wrong because of polarity; c is wrong because of the ammeter connection.)

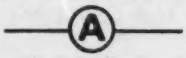
21. Which statements are correct concerning the ammeter?

___ a. measures current flow

___ b. should be connected in parallel to part of the circuit

___ c. has a schematic symbol like this:

___ d. is not sensitive to the direction of current flow

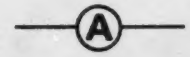
___ e. has a schematic symbol like this: 

___ f. should be connected in series

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 21

a - measures current flow

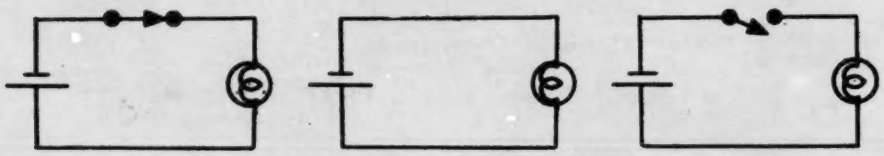
e - has a schematic symbol like this: 

f - should be connected in series

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 27. OTHERWISE, GO BACK TO FRAME 14 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 21 AGAIN.

22. When installing an ammeter in a circuit you must first de-energize, open the circuit.

Which schematic shows a de-energized circuit?



a___ b___ c___

(c) de-energized circuit

23. A circuit is de-energized when:

___ a. no current can flow.
___ b. little current flows.
___ c. a switch is closed.

(a) no current can flow.

If you have not already done Experiment #1 in the narrative, turn to page 110 of this lesson and perform the experiment prior to proceeding.

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24. When taking current readings, take the following steps:

1. De-energize the equipment.
2. Select the proper meter range for measuring the maximum amount of current expected in the circuit.
3. Connect leads, placing meter in series with the circuit, observing _____.
4. When you are clear of equipment, energize equipment.
5. Take reading.
6. De-energize equipment.
7. Disconnect meter.

(Polarity, and safety precautions for yourself and the meter)

25. Complete the steps for correctly making DC current measurements; see frame 24, and think about each step.

1. _____ equipment.
2. Select _____ for measuring the maximum amount of current expected in the circuit.
3. Connect leads, placing meter in _____ with the circuit, observing _____.
4. When you are clear of equipment, _____ equipment.
5. Take _____.
6. _____ equipment.
7. _____.

- -

(See frame 24)

26. Which column correctly lists the steps for correctly measuring current?

A

1. Energize equipment.
2. Connect leads, placing meter in series.
3. Select the proper meter.
4. De-energize equipment.
5. Take reading.
6. De-energize equipment.
7. Disconnect meter.

B

1. De-energize equipment.
2. Select the proper meter.
3. Connect leads placing meter in series.
4. Energize equipment.
5. Take reading.
6. De-energize equipment.
7. Disconnect meter.

- -

(B De-energize equipment
Select the proper meter
Connect leads placing meter in series
Energize equipment
Take reading
De-energize equipment
Disconnect meter)

A-does NOT observe safety precautions

27. Write out the steps required to measure the current flow in a circuit.

1.

2.

3.

4.

5.

6.

7.

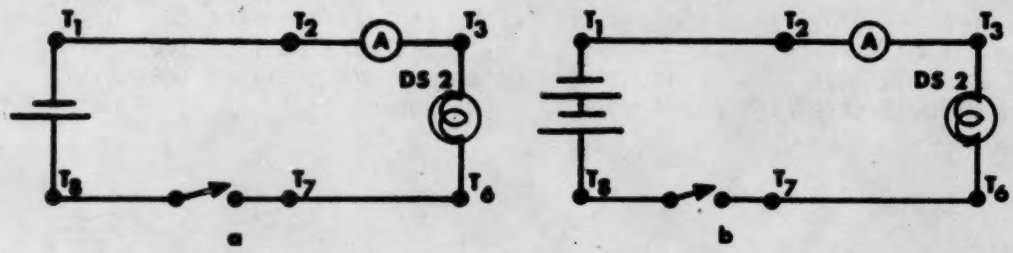
(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 27

See Frame 24

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 28. OTHERWISE, GO BACK TO FRAME 22 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 27 AGAIN.

28. With components contained in your modular kit, build the simple circuits shown below, and take current readings.



(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 28

The current in Circuit B should be greater than that of circuit A. If not, check with your instructor.

IF YOUR ANSWERS ARE CORRECT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, YOU HAVE MASTERED THE MATERIAL AND ARE READY TO TAKE THE MODULE TEST. SEE YOUR INSTRUCTOR.

IF YOU DECIDE NOT TO TAKE THE PROGRESS CHECK AT THIS TIME, OR IF YOU MISSED ONE OR MORE QUESTIONS, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU HAVE ANSWERED ALL THE PROGRESS CHECK QUESTIONS CORRECTLY. THEN SEE YOUR INSTRUCTOR AND ASK TO TAKE THE MODULE TEST.

SUMMARY

LESSON V

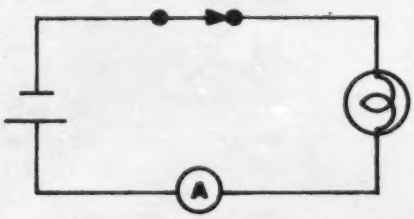
The Ammeter

Because we can neither see nor feel electrons, we must determine current by measuring some effect of the movement of charges. We could use the brightness of a lamp to do this, but the lamp indicator has three major drawbacks:

1. We cannot easily record or compare readings.
2. It is useful over a very limited range of currents only.
3. The lamp takes too much of the electrons' energy away from the work we want done in the circuit, thereby disturbing the circuit.

A device called an ammeter overcomes all three difficulties and is the normal method for measuring current flow. The ammeter indicates the current flow through it by the position of a pointer in front of its calibrated dial. The schematic symbol for an ammeter is:

An ammeter must be connected in series so that all the current to be measured flows through it. The schematic diagram for a circuit with an ammeter connected is:



If you are satisfied with your understanding of the ammeter, read "Hooking Up an Ammeter" in the Narrative for this lesson, then perform the experiment "Using an Ammeter" which follows it; if not, continue your study of Lesson V.

NOW YOU MAY EITHER TAKE THE PROGRESS CHECK OR STUDY ANY OTHER OF THE RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL QUESTIONS CORRECTLY, YOU HAVE MASTERED THE MATERIAL AND ARE READY TO TAKE THE MODULE TEST. SEE YOUR INSTRUCTOR.

IF YOU DECIDE NOT TO TAKE THE PROGRESS CHECK AT THIS TIME, OR IF YOU MISSED ONE OR MORE QUESTIONS, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU HAVE ANSWERED ALL THE PROGRESS CHECK ANSWERS CORRECTLY. THEN SEE YOUR INSTRUCTOR AND ASK TO TAKE THE MODULE TEST.